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"The oldest magazine dedicated solely to the technology and application of superabrasives."

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Laser Welding of Drill Bits

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New Cutter Technology Improves Performance 30-70% in Existing PDC Drill Bit Designs

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8

feature articles

10 Laser Welding of Drill Bits

18 Diamond Wire Slot Cutting at Mactaquac Generating Station

22 New Cutter Technology Improves Performance 30-70% in Existing PDC Drill Bit Designs

27 Study of the Influence of Cobalt Content on Polycrystalline Diamond (PCD) Mechanical Properties

departments

4 A Guest Editorial

6 Editorial

8 News and Notes

9 Announcements & Products

12 Events Calendar

26 Ad Insertion Order

FINER POINTS is the only publication devoted exclusively to the understanding, selection and application of diamond, cubic boron nitride and related materials. It is edited for recipients who are involved in some way with these "superabrasives", either as providers of the materials, producers of products containing the materials or users of these products (e.g., grinding wheels, dressing tools, drill bits, saw blades, sawing wires, cutting tools, polishing compounds, CVD film products, etc.).

8

10

18

22

27

advertisers

Apogee Precision Parts 11
Bogimac NV-SA 9
China Grinding Conference 29
Element Six .... OBC
Engis Corporation .... IBC
Funik Ultrahard Material Co. 15
Global Superabrasives, LLC 12
Henan Huifeng Diamond Co., Ltd. 21
ILJIN USA, Inc. 17
Innovative Organics - Saint-Gobain Grains & Powders 25
Lands Superabrasives 5
Luoyang Meik Diamond Co., Ltd. 6
SF Diamond Co., Ltd. 20
Worldwide Superabrasives 7
Zhongnan Diamond Co., Ltd. .... IFC

COVER PHOTO

Cover Photo courtesy of Hughes Christensen shows the Kymera™ hybrid drill bit with the new technology that combines roller cones and PDC fixed cutters into a single, patented design.

A Guest Editorial

Manufacturing Recovery Needs New Skilled Workers

Older employees leaving with experience, talent poses challenge.

CHARLIE MATHEWS

MANITOWOC — Oshkosh Corporation recently had a job fair where there were 8,000 applicants for 600 positions. The specialty truck manufacturer hasn't been able to fill them all and that doesn't surprise economist Jeffrey Sachse. "As we have moved into recovery, a major challenge is to identify what workers and skills the region needs to be more competitive," Sachse told a Tuesday gathering at The Chamber of Manitowoc County. "The big demand we have now is finding people to fill new demand," Sachse said. Many older workers in manufacturing are exiting and taking with them critical experience and skills, said Sachse, whose talk was titled, "Growth and Challenges in a Changing Economy — 2011 and Beyond." "A lot of the challenges we will face in northeast Wisconsin will be more demographic in nature, not economical," Sachse said of the anticipated surge of older worker retirements in the next decade. That's not the only obstacle. "Manufacturing has a bit of a P.R. problem among young workers," said Sachse, a Two Rivers native who is a labor market analyst in the state's Office of Economic Advisors within the state Department of Workforce Development. He said adults — including parents — don't help combat the skills shortage if they portray manufacturing positions as dirty, labor intensive and not having family-supporting wages.

LOCATING TALENT VITAL

The NEW Manufacturing Alliance sponsored a study focused on northeast Wisconsin manufacturers' plans for 2011. The study surveyed employers that had $3 million or more in annual revenue and 25 or more employees. Nearly 200 manufacturers responded to the survey... Business growth: 78 percent an increase in sales this year. Capital investment and plant modernization: 41 percent plant capital investment and 48 percent plan on plant modernization in the next 12 to 24 months. Work force growth and recruitment: Manufacturers are planning on hiring throughout each quarter in 2011. In fact, Gov. Scott Walker told a Manitowoc Grey Iron Foundry audience Thursday that of 13,000 new private sector jobs created in Wisconsin the first two months of 2011, about 8,000 were in manufacturing. The alliance survey found, on average, 40 percent of manufacturers plan on hiring; however, 29 percent are having difficulty locating talent in the region. "Manufacturing drives the state's and local economy and manufacturing has paced the recovery" from a recession that officially ended in the third quarter of 2009, said Sachse, a lecturer in the Masters of Public Administration program at the University of Wisconsin- Oskhosh. For long-term manufacturing sector strength, Sachse believes it will be crucial for business and education to work together including re-training of adult learners to acquire necessary skills. That will mesh well with the stated mission of the DWD: "Advancing Wisconsin's economy through a leading workforce development system that attracts, creates, and retains jobs, and empowers individuals to become self-sufficient."

Written by Charlie Mathews
Manitowoc, Wisconsin Herald Times Reporter

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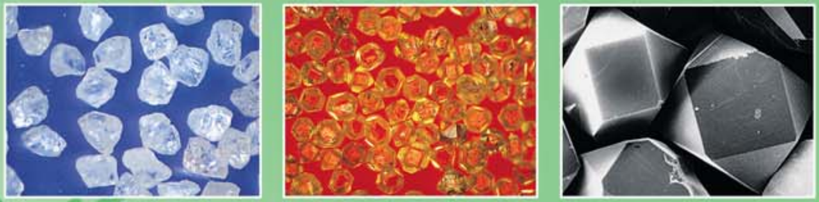

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Selling Products and Promoting Your Company in Tough Times ...

TERRY KANE, Editor

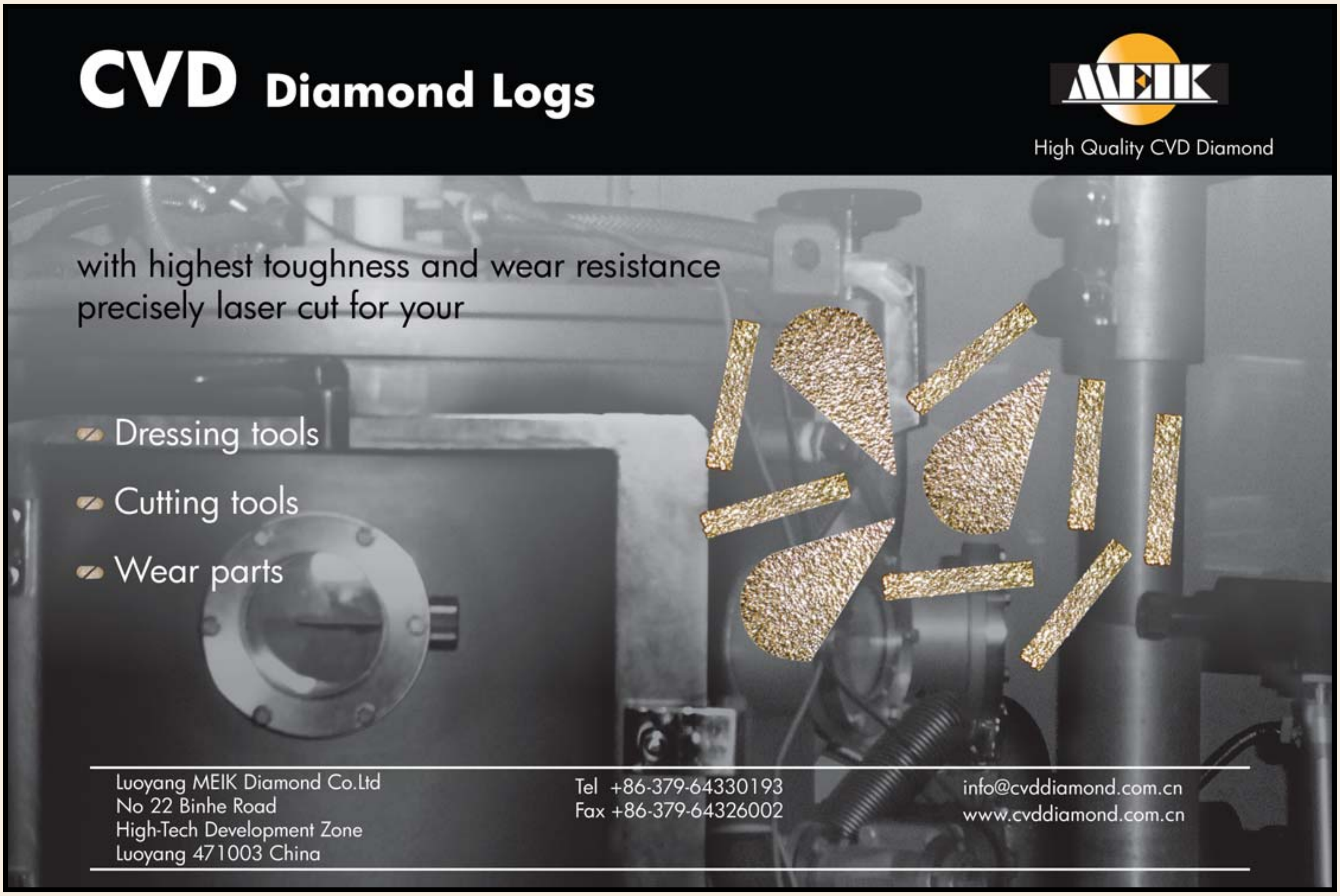
This is coming from an old marketing guy, but to keep a business in the forefront and fresh in the minds of our customers, one thing that should be stressed is that any marketing program needs to be a “program” not a hit and miss adventure. In the world of communications there are many ways to spread the word, but with a limited budget, what are the best choices?

“Do you have a product to sell”? If you don’t, you can stop reading right here. Assuming the answer is yes, develop your literature, brochures, case histories, data sheets, etc. so you have materials you can provide to your customers. These can be used as handouts, direct mail pieces or replies to those who have questions or inquiries. Next, you need to actively seek ways to “spread the word” about your product and your company. In this day and age there are many places to put your energy and money. The tough decision may be where to get the most for your investment. Look at the entire spectrum of tools you could utilize such as mailings, face to face visits, tradeshows, press releases, conferences, Internet (including email blasts and websites) and of course advertising. One thing usually does not work all by itself, a combination needs to be employed to gain the best exposure and recognition.

A well-rounded Marketing Program will have a little bit of each tactic depending on the budget, time constraints and available personnel.

Mailings using regular postage have gone through the roof, but it still has its place if you have a good qualified mailing list. ***Cold calls and face to face visits*** are an outstanding way to seal the deal and keep lines of communication open. Most people still like that personal touch and confidence builder that this brings, but travel costs are raising and coverage is very limited. ***Tradeshows and conferences*** are an excellent way to meet a lot of people, especially if your customers are there in large numbers. ***Press releases*** are a great way to keep your message out there and current. If you keep them unique and interesting with a good photo, most magazines will print them. If you have a ***Website*** with current information, search engines will find you on topics related to your company. ***Email*** is a great way to spread your message, but be careful, while inexpensive this can have a negative effect if the recipient can’t readily remove their name from your list.

Advertising does two things for a company, it not only introduces or “sells” a product, but it does something else that is critical… IT GETS YOUR COMPANY IN FRONT OF CUSTOMERS AND POTENTIAL CUSTOMERS… plus there is a “pass around feature that makes advertising carry on for an extended period of time. Brand awareness is crucial in this industry as your customers (and potential customers) are besieged from every direction and media. To keep your customers and ward off companies trying to cut into your business you need to have a focused and well conceived approach. Periodic ads herald that a company is alive and well! The death knell for a company is when anyone asks if the company is still in business. Let everyone know your company is alive and well!



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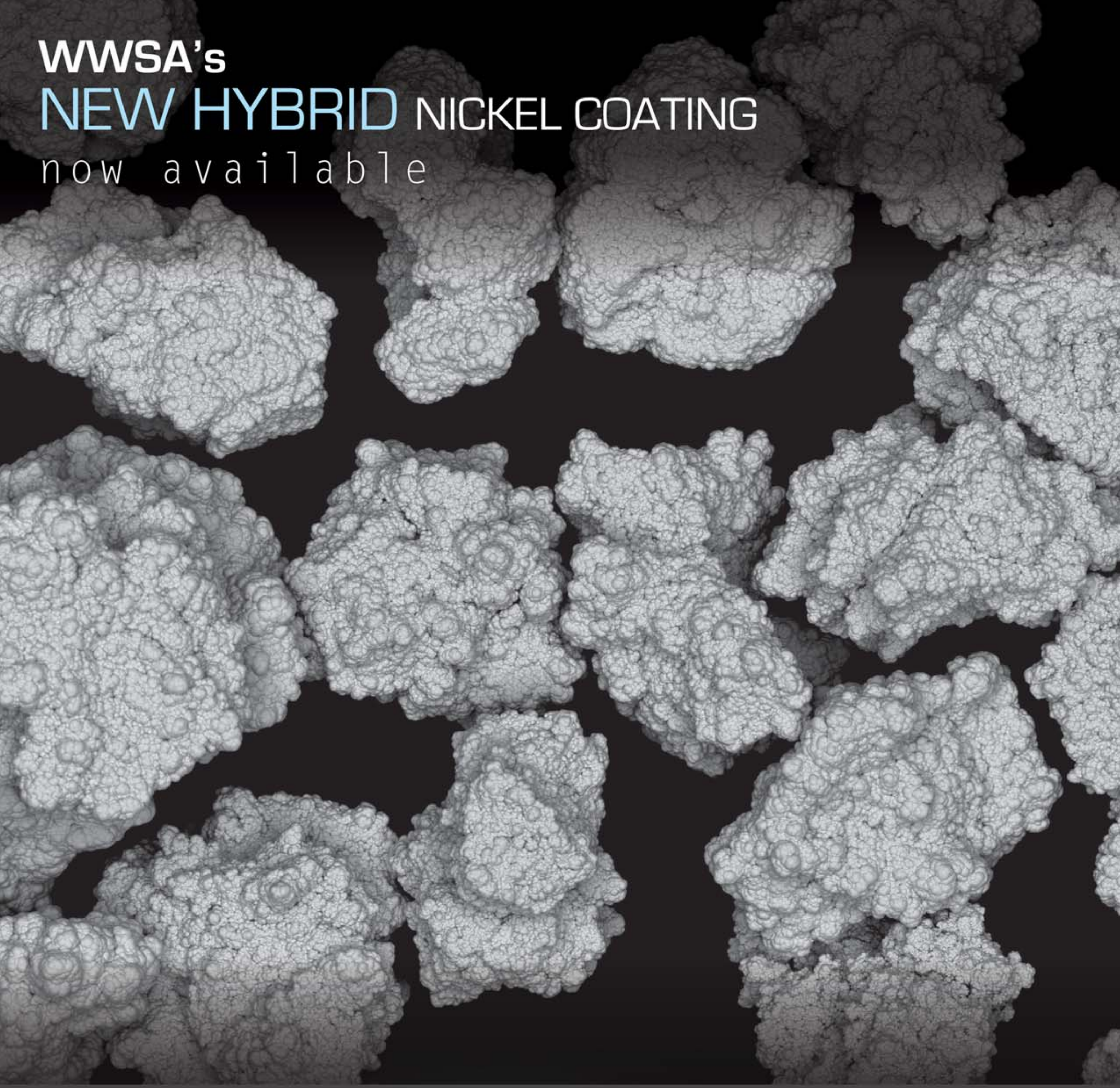

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NEWS and notes

CINETIC LANDIS CORP. – CITCO TOOLS RELOCATES TO NEW, STATE-OF-THE-ART FACILITY

Concord Twp, Ohio – CITCO Tools, one of North America's largest manufacturers of custom engineered cutting tools, has moved to a new state-of-the-art facility located at 7605 Discovery Lane, Concord Twp, Ohio 44077. The modern facility combines 13,290 square feet of office space and 35,510 square feet in manufacturing space, located on over 8 landscaped, green and treed acres. The facility is strategically located in close proximity to routes I-90 and State routes 44 and 2. CITCO Tools will optimize the space allocated for both production and office spaces. Here CITCO Tools will manufacture polycrystalline diamond and polycrystalline cubic boron nitride cutting tools, diamond and cubic boron nitride grinding wheels and diamond dressing tools of higher quality levels and productivity, in a more efficient facility designed to support lean manufacturing and incorporating optimized material flow, optimized manufacturing processes and resource efficiency. More information can be found on the company's website at www.fivesgroup.com/tools

WALL COLMONOY INSTALLS A HIGH-TEMPERATURE VACUUM FURNACE AT LOS LUNAS, NEW MEXICO FACILITY

Madison Heights, MI – Wall Colmonoy announced it has installed a Centorr Workhorse® Vacuum Brazing Furnace at the Los Lunas, New Mexico facility. The new furnace, customized for Wall Colmonoy's specific needs, is able to process material under high-vacuum and partial pressures with excellent process control. The furnace's Yokogawa Process Control System with an HMI interface will help technicians maintain effective operation and control of the furnace as well as provide data with which to make operational decisions. Brazing parts and components for the aerospace, automotive, defense and energy industries where braze quality is critical to the longevity, safety and efficient function of jet engines, turbine blades, missiles, heat exchangers and nuclear reactor components outside the core, Wall Colmonoy's experienced engineers and technicians will use the new vacuum furnace to continually test braze quality. More information is available at www.wallcolmonoy.com

BOEING LAUNCHES A 737 NEW ENGINE FAMILY WITH COMMITMENTS FOR 496 AIRPLANES FROM FIVE AIRLINES

Seattle, WA – Company's board of directors has approved the launch of the new engine variant of the market-leading 737, based on order commitments for 496 airplanes from five airlines. "The re-engined 737 will allow Boeing to continue to deliver the most fuel efficient, most capable airplane with the lowest operating costs in the single-aisle market," said Boeing Commercial Airplanes President and CEO Jim Albaugh. "This, coupled with industry leading reliability and maintainability, is what customers have told us they want. As a result, we are seeing overwhelming demand for this new and improved version of the 737. We are working with our customers to finalize these and other agreements in the weeks and months ahead." The Boeing 737 is the world's most popular and reliable commercial jet transport. The 737 family has won orders for more than 9,000 airplanes. The Next-Generation 737 program has continuously improved the products, features and services that provide increasing value to customers. Today's Next-Generation 737s are up to 7 percent more fuel-efficient than the first airplanes delivered in 1998. Boeing forecasts global demand for more than 23,000 airplanes in the 737's market segment over the next 20 years at a value of nearly $2 trillion USD.

CHROMALLOY TO BUILD R&D CENTER FOR TURBINE PARTS

Chromalloy Corp. is developing a new research-and-development center for its gas turbine engine components product line in Palm Beach Gardens, FL. The company, which recently started up a $30-million investment-casting foundry in Tampa and is developing a $5-million ceramic core plant nearby. The new Technology Center of Excellence will unite Chromalloy technicians currently located at engineering centers throughout the company, including the Turbine Design Analytics Group in Stuart, FL. New staff also will be hired for the Center, which will occupy a leased 30,000-ft2 location with labs, office space, and a 10,000-ft2 warehouse. Chromalloy bills itself as "the world's largest independent supplier" of turbine airfoils and other critical aerospace engine components for commercial and military jets. It also provides component parts for industrial gas turbines. As well as producing investment cast parts, Chromalloy has engine service and repair centers worldwide.

& Announcements PRODUCTS

MAG'S CRYOGENIC MACHINING TECHNOLOGY APPROVED FOR TITANIUM CUTTING ON LOCKHEED MARTIN F-35 FIGHTER

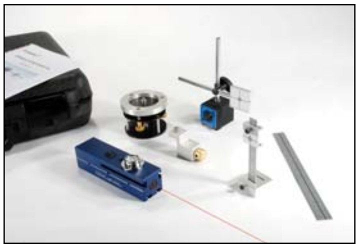
Through-tool cooling with liquid-nitrogen supports fighter's affordability with faster metal removal rates and longer tool life. - *Erlanger, Kentucky, September 15, 2011* – MAG's groundbreaking lowflow cryogenic titanium machining process has been approved by the government for use in production of the Lockheed Martin F-35 Lightning II stealth fighter. According to Lockheed Martin, when broadly applied, this new technology could improve affordability and efficiency in the production of the F-35, which is approximately 25 percent titanium. Cryogenic titanium machining increases cutting-tool life up to a factor of 10 and doubles the material-removal rate, compared to conventional machining methods in certain applications. According to Mike Packer, Vice President of Manufacturing Strategy & Technical Integration at Lockheed Martin Aeronautics, "This is a prime example of an SBIR-developed technology transitioning from the research and development phase to a system that can enhance affordability for near-term military projects like the F-35." ***For more information about MAG, please visit: www.mag-ias.com***

ELEMENT SIX PUSHES THE BOUNDARIES OF CUBIC BORON NITRIDE CAPABILITY WITH THE LAUNCH OF ABN900

New solution performs up to 55% better in maximising tool life. - Element Six announces ABN900, a new high strength cubic boron nitride (CBN) abrasive for single layer tools. The material has been developed in response to increased requirements from the aerospace and automotive sectors for a product that can better the performance of high strength electroplated grinding tools to meet the high standards of engineering component parts. ABN900 has been specifically developed by Element Six for use in high strength electroplated grinding tools and will be part of a range of eight CBN products used in grinding applications. ABN900 enables higher levels of grinding performance, for faster material removal and longer tool life, enabling maximized efficiencies in the production of aerospace and automotive components. ***For further information please visit www.e6.com/abn900***

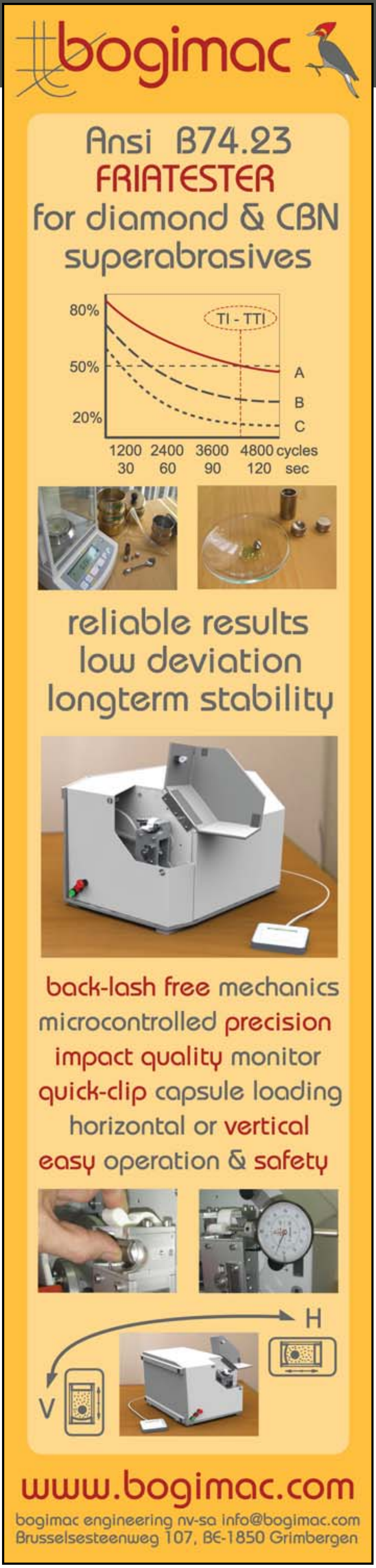
SHORTER SET-UP TIMES WITH THE SCHUNK ROTA THWPLUS

The ROTA THWplus quick jaw change chuck stands alone in flexibility and set-up efficiency. In today's competitive manufacturing world, single purpose chucks will not stand the demanding changes. In less than 60 seconds, a complete jaw set can be changed with a repeatability of less than 0.0005" which eliminates the need to re-bore jaws. A unique wedge-bar actuation system allows this chuck to offer larger through holes with faster spindle speeds, coupled with the Quick-Jaw-Change-System. The ROTA THWplus increases time in the chip, not in the set-up, which maximizes the throughput and ROI of any lathe. A selection of modular sleeves are available for through spindle coolant, part ejection, closed center sealing, or as an adjustable part stop, giving you the flexibility you need in all process improvements. ***For more information, visit www.schunk.com***



UNIQUE, NEW LASER ALIGNMENT KIT FOR INDUSTRY

Peabody, Massachusetts, August 2011 – Pinpoint Laser Systems® is introducing the new Pinpoint Proline Alignment Kit – a visual laser system for checking and measuring straightness, flatness, squareness, parallelism, leveling, and many other tasks. This kit combines the features of a transit, an infinitely long straightedge, and laser alignment system all in one compact, portable, versatile product. Precision laser alignment for production, maintenance, and plant engineering projects, both large and small, has never been so easy. This level of accuracy is ideally suited for setting straight machinery runs, aligning production equipment, transferring mechanical points, locating shafts and bearing mounts, aligning belts and pulleys, and countless other industrial tasks. ***Learn more at www.pinlaser.com/guides.html***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Laser Welding of DRILL BITS

By GERHARD WEBER, PHD – Dr. Fritsch Sondermaschinen

Photo of BSV200

Photo of BSM220

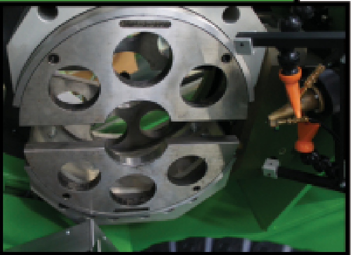

Photo of BSM220 – 2 Half-Shell Gripper, Specific to Tube.

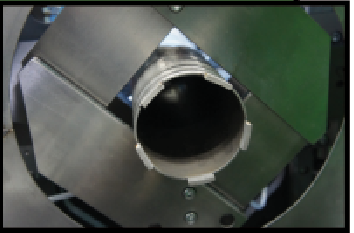

Photo of BSM300 – 4-Point Gripper, Not Diameter Specific.

Photo of Torque Testing on a Drill Bit

The laser welding of diamond tools has a long tradition. Especially in the USA, diamond saw blades have been commercially laser welded since the 1980s. At that time, Norton and NED hade pioneered the blade market with their at that time innovative technology. The drill bit was long in the shadow of the diamond blade. Lower demand, smaller production runs and, due to geometrical reasons, higher transportation costs made it less attractive to automise the production. However, as the world demand for drill bits is steadily rising, the laser welding of drill bits becomes more and more attractive. Lower production costs due to a very fast welding process with very little labour demand, no need for the expensive silver solder and a high stability of the drill bit, especially when used without cooling water leads to an increasing market share of welded bits.

Different Welding Concepts

The first commercially available drill bit welding machine (BSV200) was marketed in 1992. That machine was basically working like a lathe. The segments were placed in a jig that was pressed onto the tube. That tube was clamped before in a big chuck that originated from a lathe. Then the whole assembly was turned and a stationary laser beam was used to weld segments and tube together. Several companies copied that design and some machines of that type are used until today. The drawback of this system was that every diameter and every number of segments needed a new jig. The advantage was that the system was quite cheap and the chuck could adapt to all diameters.

A later design (BSM220) used a chuck that consisted of 2 half-shells that were clamped around the tube by a pneumatic gripper. The segment was placed one by one onto the tube and was spot-welded into place. After spot-welding all segments, the tube was rotated and the stationary laser beam was used to powerweld all segments.

The advantage of the BSM220 system was that no jig was needed anymore. The number of segments, the clearance and the segment size was not depending on exchange parts but could be set on the operating panel. Also the pneumatic chuck would allow a more automised loading of the machine.

The BSM220 design still needed some parts (the half-shells) that had to be changed for every new diameter. The spot welding also caused some problems. Especially with the tolerances of the tube, some welding spots were too weak to hold the segments in place. The productivity of the whole system was also not very high. The latest design (BSM300) uses a 4-point clamping chuck that can be used for diameters from 8mm (app. 0.3") until 300mm (app. 12"). Additionally, the segments are immediately welded by the use of a 3-axis-laser-head. That makes the machine fast and - even more important - very easy to set up.

Problems of Laser Welding

In the past, customers that were laser welding their drill bits, complained about insufficient quality of the tubes. The tube suppliers had problems to fulfil the tight tolerances that were needed to obtain the desired welding quality. Although it seems not too difficult to machine a tube on a lathe to acceptable flatness and roundness, the required tolerances are much tighter than they used to bee for a brazed tube. As the laser beam is only app. 0.25mm (app. 1/100") at the focal point, the face run-out should not exceed 0.1mm. This seems to be a too tight tolerance to produce tubes for acceptable prices.

Machine Requirements

To overcome the dependability on the supplier side, the task was to design a self adjusting machine that can measure the face-run-out and the roundness of the tubes and to adapt itself to these measured tolerances. That had to be done in conjunction with an adequate machine concept that allows a very fast setup, a fast cycle time and an easy operation. Ideally, that concept would also allow the use of a tube handling unit for full automisation of bigger batches.

Quantification of the Required Self Adjustment System

After the machine was designed and a first prototype was built, the customers wanted to know, how big the effect of this self adjusting feature would be. The task was therefore to measure the quality of tools with and without the self adjusting feature. Therefore it was decided to do some extensive tests on the laser welding of drill bits to understand the complex connection of the huge amount of parameters that could be varied, applying the laser welding technology.

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Calendar of EVENTS

To have your event or conference listed, please send information to: Finer Points Event Calendar • P.O. Box 29460, Columbus OH 43229 • Fax 614-797-2264 or email: tkane-ida@insight.rr.com

October 4-6
Wisconsin Manufacturing & Technology Show
West Allis, WI USA
www.expoproductionsinc.com/tool_home.htm

October 18-21, 2011
SAE 2011 AeroTech Congress & Exhibition
Centre de Congres Pierre Baudis & Toulouse Expo, Toulouse, France
www.sae.org/events/atc

October 19-20, 2011
Advanced Manufacturing & Technology Show
Dayton, OH USA • www.daytonamts.com

November 9-11, 2011
UAMA Fall Meeting
Newport Marriott
Newport, RI • www.uama.org

November 11-13, 2011
China International Abrasives & Grinding Exposition
Zhengzhou International Convention and Exposition Centre, Henan, P.R. China
www.abrasivesexpo.com

November 14-17, 2011
DoD Maintenance Symposium & Exhibition
Fort Worth Convention Center,
Fort Worth, Texas USA
www.sae.org/events/dod

November 14-19, 2011
CSDA Operator Certification Training
St. Petersburg College
2465 Drew Street
Clearwater, FL 33765 USA
For more information info@csda.org

Calendar Dates for 2012

February 19-22, 2012
SME Annual Meeting & Exhibit
Seattle, Washington USA

May 2012
Industrial Diamond Association ANNUAL MEETING
Hyatt Regency Gainey Ranch
Scottsdale, Arizona USA
www.superabrasives.org

April 30 – May 3, 2012
Offshore Technology Conference (OTC)
Reliant Park
Houston, Texas USA • www.otcnet.org

May 22-23, 2012
WAI Operations Summit & Wire Expo
Omni Dallas Hotel Dallas, Texas, USA
www.wirenet.org/events/wireexpo/index.htm

September 10-15, 2012
International Manufacturing Technology Show
McCormack Place • Chicago, Illinois USA
www.imts.com

Calendar Dates for 2013

May 6-8, 2013
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www.intertechconference.com

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The Machine Setup and the Test Setup

A new prototype (the BSM300) was used to laser weld the drill bits. The segments were welded onto the tubes and always a standard set of parameters was used, varying only one parameter at a time. The quality of the welding was judged by breaking off the segments. The higher the achieved torque, the better the result. The segments were always broken off from inside to outside. A digital torque wrench was used to eliminate clamping force and all other unrelated forces apart from the bending force at the joint. The digital torque wrench recorded the maximum torque and displayed it directly.

The Welding Parameters

- The machine uses a Rofin Sinar DC025. That is a CO2-Laser with 2.5kW power.
- Actual welding power: 2,125W
- Welding speed: 1,400mm/min
- Welding angle: 3°
- Focal length: 200mm
- Mirror protection: Cross jet
- Welding gas: Argon, 50 + 20 l/min
- Tube diameter: 100mm (app. 4”)
- Tube length: 510mm
- Wall thickness: 2mm
- Tube material: laser weldable steel
- No of segments: 9
- Clamping force of the tube: 1,200N
- Segments dimensions: 24*3.5*9mm
- Segment bond: V30-608 (Dr. Fritsch), main content: Carbonyl Iron
- Outside clearance: 0.75mm

The complete setup could be described as relatively robust. The rather long focal length of 200mm produces a large focal point that reduces the dependability on exact geometrical precision. The reduced welding speed and reduced laser output also widens the welding seam and the bond is also known as easy weldable without giving super-high torque values. All in all, it was tried to mirror a setup that would be used on a shop floor rather than in a laboratory.

The Test Programme

1. Measurement of roundness and face run-out in test fixture
2. Measurement of roundness and face run-out in the welding machine (BSM300) and comparison with #1
3. Measurement of roundness and face run-out with variation of the clamping force
4. Variation of the axial offset to find the ideal welding position
5. Welding with and without run-out correction to evaluate the value of this function

Testing and Test Results

Measurement of roundness and face run-out in a test fixture. Twenty tubes from a European supplier were procured, marked with a number and measured. The tubes were measured in a test fixture that was designed for that purpose.

The measured results:

	ROUNDNESS	FACE RUN OUT
Average	0.22mm	0.15mm
Minimum	0.05mm	0.06mm
Maximum	0.50mm	0.32mm
Standard Deviation	0.123mm	0.063mm

The roundness was as expected. The values for face run out however were quite large, the result was far from good. If the focal point has a diameter of app. 0.25mm, a maximum run out of 0.32mm would clearly reduce the stability of the laser welding joint by far. An improvement of any welding results by using the front run out correction option could therefore be expected.

Measurement of the Tubes Within the Welding Machine

The same tubes were then measured in the welding machine by the inbuilt sensors. The difference of the measured values of the measuring fixture and the welding machine were within 0.1mm with most values differing by not more than 0.05mm. That result showed, that the clamping system is precise enough for this application.

Measurement of Roundness and Face Run-Out with Variation of the Clamping Force

The idea was to check, if the clamping force would have any influence on the roundness or face run-out of the tubes. The previously on the test device measured tubes were clamped in the machine and measured. The clamping was released and the tubes were re-clamped with

Photo of Digital Torque Tester

Photo of Stock of Tubes, Ready for Measurement & Testing

Photo of Test Fixture, Front

Photo of Test Fixture, Rear

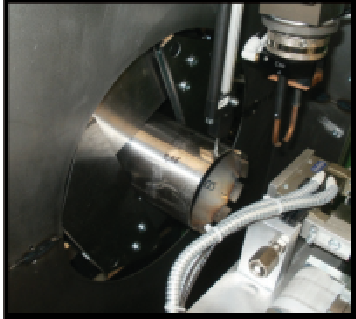

Photo of Test Fixture, Rear

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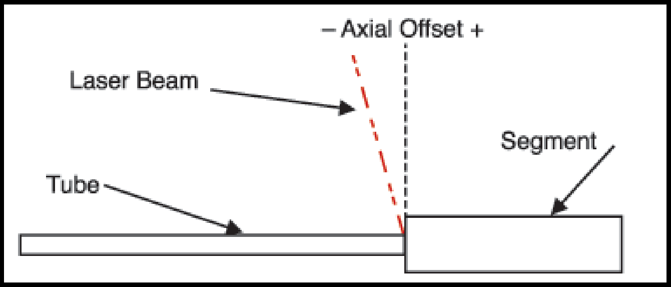
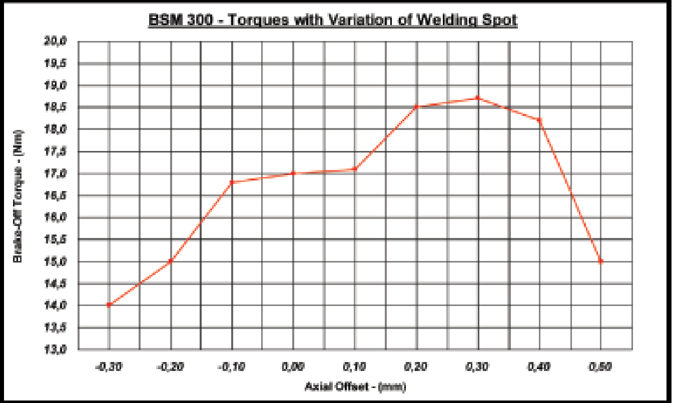


Sketch: Description of Axial Offset



Graph: Brake-Off Torques Over Axial Offset

Bit No	Compens.	Start Point	Offset	Mean	Max	Min
11	on	0	0.2	20.3	24.1	17.1
12	off	0.28	0.0	17.7	23.4	10.7
13	on	0	0.2	18.6	19.9	17.3
14	off	0.12	0.2	16.1	17.5	13.8
15	off	0.14	0.2	16	20.5	8.9
17	off	0	0.0	18.7	23.5	10.6
20	off	0.26	0.3	10.2	17.7	7.9
5b	off	0.21	-0.1	14.2	19.2	8.0
8b	off	0.17	-0.1	10.7	19.8	8.0
9b	off	0.29	0.2	8.3	17.1	0.0
10b	on	0	0.2	17.3	23.1	15
12b	on	0	-0.1	18.5	23.8	16.5
20b	on	0	0.2	18.7	23.7	15.8

Table: Brake-Off Values With & Without Run-Out-Compensation

a new load. The clamping force was varied between 400N and 2,000N. The result was that the values of the run-out and roundness were very similar to the previous measured values. The clamping force in the above dimensions had virtually no impact. If at all, there was a tendency of the run-out and roundness deviation to get smaller with growing clamping force.

Variation of the Axial Offset to Find the Ideal Welding Position

A number of tubes were welded with variation of the axial offset. The idea was to find the offset that would give the highest torque values. To eliminate the tolerances of face run-out, the run-outcorrection- option was switched on.

The recorded brake-off-torques were surprising. Below is a graph of the average torques, received with a variation of the laser beam position in axial position.

The highest torque was not recorded directly at the edge of the tube but quite far into the segment. It is remarkable, that the highest values were obtained at a distance from the edge that was bigger than the beam diameter itself. The result was that the best torque could be achieved with an offset of 0,3mm towards the segment side. On this maximum peak, a deviation to the tube side would result in a only marginal reduction in strength. A deviation towards the segment side would result in a rather steep reduction of the strength. In other words: The position of the maximum torque would give best results but would be more risky than a position more towards the edge of the tube. There the strength would be less but a deviation would not have too much negative influence.

Comparison of Welding Strength With and Without the Run-Out-Compensation

For the next test run, a number of tubes were welded with the run-out-compensation switched on (like in 9.3) and a number of tubes were welded with the option switched off.

The tubes 5b-12b were re-used tubes that were just cut off with a belt saw. The values showed a clear tendency: The average torques were better, when the run-out-feature was active. However, that was predictable. What was much more important was the fact, that the minimum values with the compensation activated were never below 15Nm. If segments of a drill bit do brake off, it will always be the weakest ones. Therefore the average and the mean values are not so important as the minimum torques that could be guaranteed. A calculation of the standard deviation showed also that a standard deviation around 4Nm without the compensation and of around 2Nm with activated deviation could be obtained.

SUMMARY

The problem of laser welding drill bits is not the overall stability of the welding seam, it is the one or two segments that have the weakest welding seam. If the welding position is measured before each segment is welded, the risk of loosing these segments can be eliminated.

The tests showed clearly that standard tubes for drill bits came with wide production tolerances. The producers of these tubes are reluctant to provide better tolerances, as the required precision is directly connected to higher cost. The roundness tolerances result in a deviation from the requested clearance of the segments, if the welding machine does not measure and correct this roundness before every welding. The face run-out of the tubes result in a misplacement of the welding seam, if the machine can not automatically correct this run-out. Without run-out correction, the average welding strength was significantly lower than with the correction. Much more important was the minimum obtained welding strength. Without the run-out correction, the minimum welding strength was much lower and thus the risk of segment loss was much higher. Especially if the welding position was placed off the tube edge into the segment side to obtain high welding strength, the values with the run-out correction switched on were much more reliably, giving much more process stability and product safety. ■

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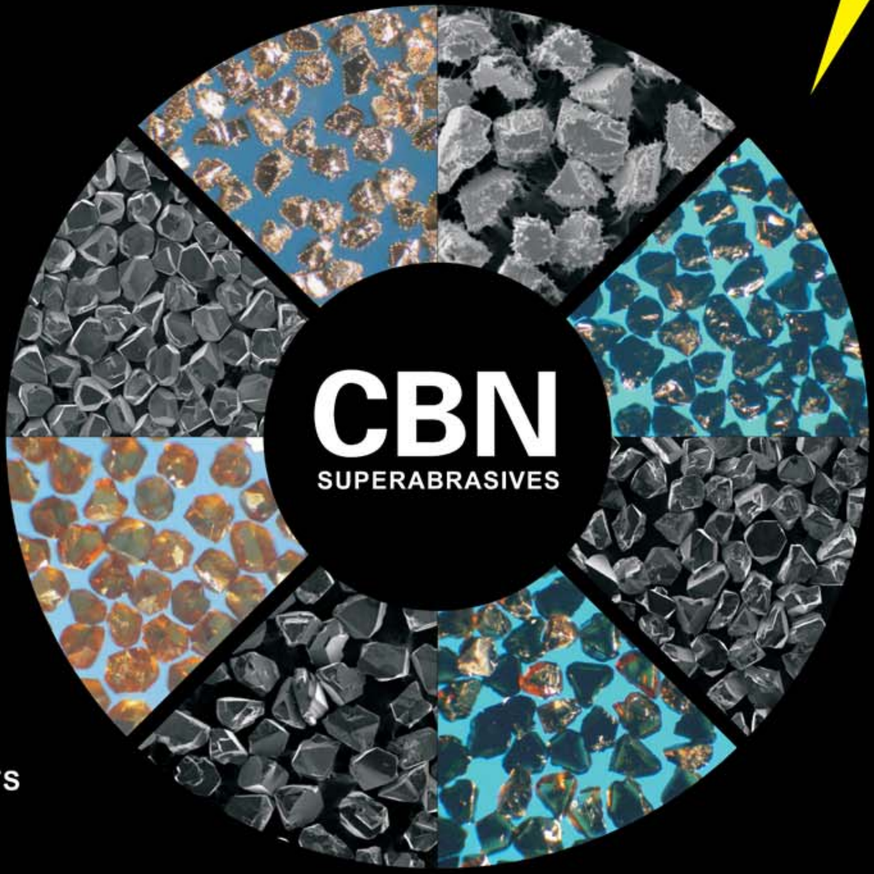

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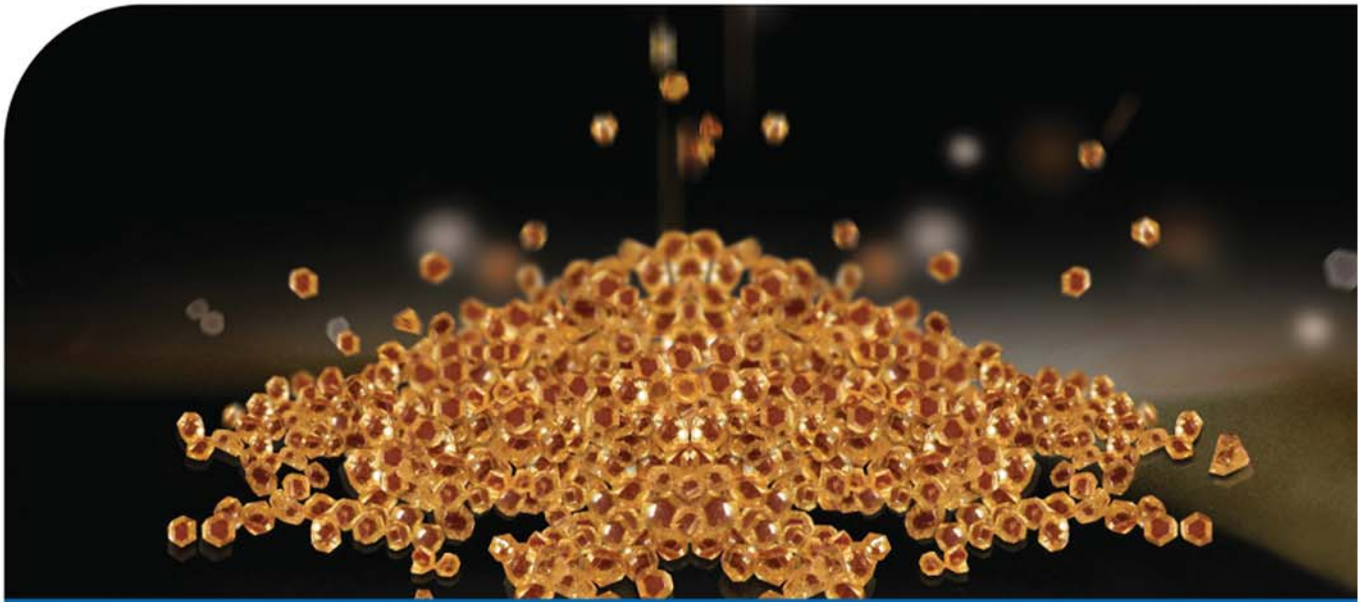

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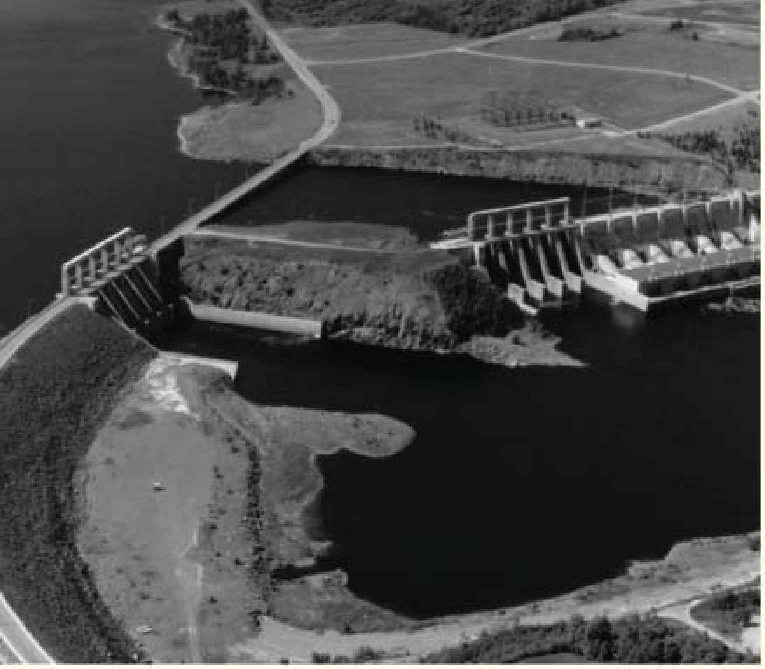

Diamond Wire Slot Cutting at Mactaquac Generating Station

To Relieve Concrete Stress Caused by AAR

**By: Joel Shebesta, Cutting Edge Services Corp. and
Michael Steeves, P.Eng. Michael Steeves, P.Eng., NB
Power Generation, Mactaquac Generating Station,
New Brunswick, Canada**

Alkali Aggregate Reaction (AAR) is a chemical reaction in hardened concrete that causes it to expand if unrestrained, or develop large compressive forces if constrained. Many concrete dams and structures throughout the world suffer from AAR. Constant diligence and continued remedial actions are required for these structures. One such action employed by Mactaquac Generating Station is cutting vertical slots through the structures via diamond wire sawing.

The Mactaquac Generating Station, which is owned and operated by New Brunswick Power, is located on the Saint John River, approximately 20 kilometers upstream from the city of Fredericton, New Brunswick, Canada. The station is the largest hydroelectric generating facility in the Maritime Provinces. Constructed in stages between 1964 and 1980, this facility has an installed capacity of 672MW produced by six turbines. This facility consists of the intake structure, two concrete spillways, diversion sluiceway, and the intake spillway. Each structure contains five, 45 feet (13.7m) wide X 53 feet (16.1m) high spillways. The structures were constructed in stages with the initial head-works structures, powerhouse, units 1 and 3 and the substructures of the powerhouse being commissioned in 1968. Unit 4 was commissioned in 1972 and units 5 and 6 were commissioned in 1979 and 1980, respectively.

BACKGROUND

Evidence of distress in the concrete structures at Mactaquac was first noticed in the mid-1970s with the increasing opening of a longitudinal joint in the powerhouse substructure. By the early 1980s leakage through horizontal joints in the spillway, intake and diversion sluiceway structures were evident. At this point NB Power decided to install instrumentation in the foundation rock and within the concrete substructure to check for the possibility of a phenomenon, such as rock swelling, being the cause of distress. In 1985 spillway gate 10, adjacent to the intake structure, was found to be obstructed. A differential displacement of the spillway end pier toward the gate opening in excess of 1 inch was noted. Further investigations showed the end pier of the spillway was cracked internally. It was about that time that the cause of the problem and movements was positively identified as alkali aggregate reaction.

WHAT IS AAR

AAR is an internal reaction that occurs when the alkalis in cement react with susceptible aggregate particles. There are two main types of AAR, alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). ASR is much more common among the two and the type of concrete growth impacting the structure at Mactaquac Dam. During the process of ASR a gel is formed around the aggregate. If the gel is exposed to moisture, usually if the relative humidity of the concrete is higher than 80%-85%, it expands causing the concrete mass to expand. Results of this expansion on large concrete structures can be unsightly cracking although structurally the integrity may not be impaired. However, major operation and maintenance problems may occur, such as binding of gates, cracking of piers, and misalignment of equipment such as the generators.

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CONDITIONS REQUIRED FOR AAR

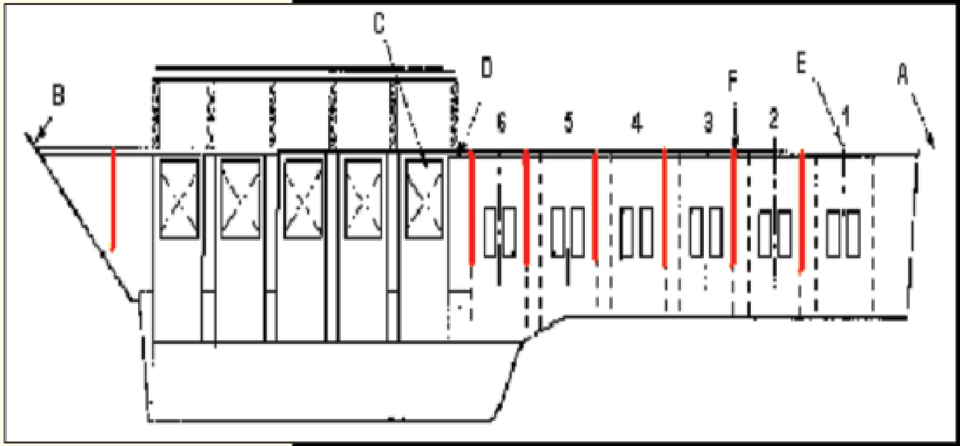
High alkali content of the cement, Reactive aggregate and High moisture/water.

REMEDIAL EFFORTS TO CONTROL AAR

All concrete affected by AAR does not continue to expand throughout its useful life. This could be due to loss of moisture, but more commonly from the depletion of alkalis. The chances of a successful repair of structures that continue to exhibit AAR expansion are very low. Structures such as Mactaquac Dam can have their useful lives expanded by implementing maintenance programs to alleviate the effects of AAR. Since the 1980s at Mactaquac, various remedial measures performed at the head works include: - Modifications to the gates, guides, and towers of the spillway, diversion sluiceway and intakes. - Chemical and cement grouting of the various structures to control leakage. - Reconstruction of bridge deck expansion joints at the spillway and the diversion sluiceway to re-establish eliminated clearances. - Slot cuts

SLOT CUTTING PROGRAM:

After the problem of expanding concrete was confirmed, it was decided that slot cuts would be installed in the intake structures to relieve deformation of the spillway and piers. The first slot cut was made in 1988 in the intake structure. The slots have reduced and balanced the deformations within the structures, relieved the structural distress and improved equipment operation. Two side effects of cutting the concrete are: (1) that it increases the expansion rate of the concrete due to the stress dependent nature of the concrete growth, and (2) unless the slots are very wide, periodic re-cutting is required. Instrumentation located throughout the structures are recorded and used to determine the frequency of each re-cut. In general the intake cuts are made on a three year cycle, the diversion on a two year cycle, and the powerhouse locations are cut on a six year cycle. To date there have been 28 slot cuts made. Cuts are made to ensure they are below any of the openings and embedded parts that may be affected by the expansion. Below this point the mass concrete is continuous. The increase in stress in this area does not cause any damage.



Intake and Spillway Structure Downstream Sectional Elevation

A – East Abutment
B – West Abutment
C – Spillway Gate 10
D – Spillway East End Pier
E – Centerline of Unit 1 Intake
F – Slot Cut at Construction Joint

Location of Intake Slot Cuts

DIAMOND WIRE SAW EQUIPMENT

Several models of diamond wire saws have been employed for slot cutting at Mactaquac. Most units were 40-50 HP electric motor driven hydraulic systems that allow ramping up and down of wire speed, along with changing direction if needed. In 2010, the wire saw system looked like the artist rendering below that shows a wire fed through holes in a wall and "pulling" the wire through the structure. The "pull" technique was used to re-open the slot in the Diversion Dam Structure. After the wire saw advances along its track system to take up slack created by pulling the wire through the structure, the machine is stopped. The wire is either cut or pulleys are added. Then, the machine is reset and the next "stroke" is pulled.

The "push" technique was utilized to re-cut the intake slot between monoliths 4 & 5 in 2010. This is illustrated in Figure 1. "Push" cutting or "downhole" was done by lowering pulleys into a cofferdam on the upstream face, into pilot holes in the deck and by various pulleys located on the downstream face.

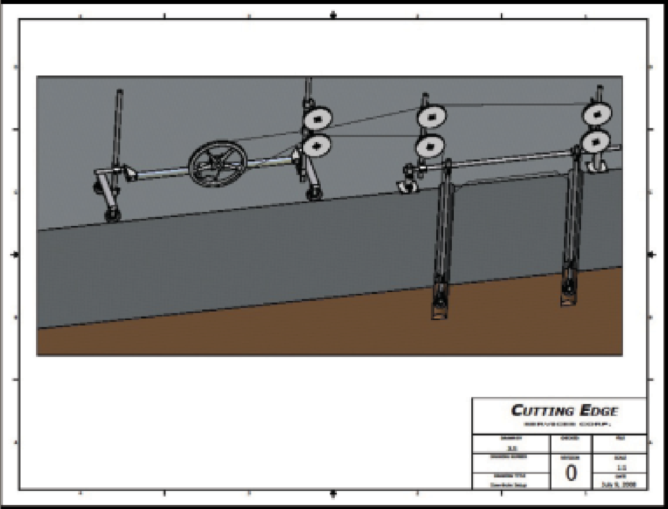


Figure 1 – Cutting Edge

A drawing of the intake structure slot 4/5 cross section is in Figure 2.

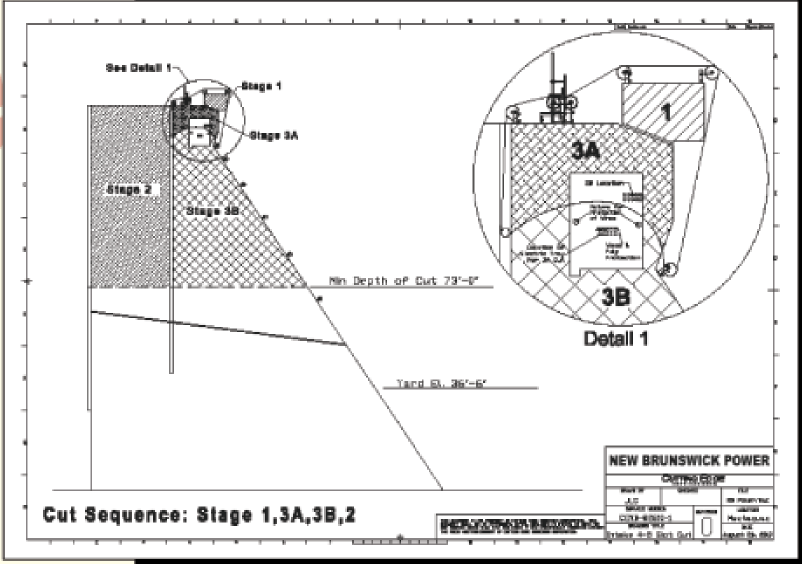
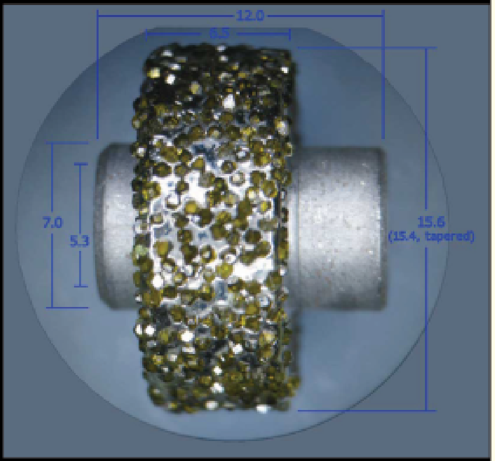


Figure 2 – New Brunswick Power

The slot was cut in stages, from the top down. The first stage pushes the wire into the gallery and close to an active electric cable tray. This cut was carefully monitored to prevent severing of the cables. Then the wire was cut and the cables moved upward. More pulleys were added and the wire was reconnected for completion of the lower stage. When the wire reached the minimum cut depth (22m / 73'-0"), the "down" pulleys were brought up. Cutting of the upstream stage was then performed, using downhole systems in the cofferdam and the pilot hole.

THE DOWNHOLE PULLEY SYSTEM

Several techniques have been utilized to "push" the wire down the pilot holes and cofferdams. In 2010, a unique hydraulic driven machine was fabricated to feed 3.3m sections of aluminum tubing downward. The system is capable of plunging down 33 meters, but less than that was needed to reach the minimum slot depth. The machine is shown:



Pictures of the Diamond Bead & Wire Assembly

DIAMOND WIRE

Currently all cuts at Mactaquac are maintained using 15mm electroplated diamond wires. In 2010, a directional rubber injected wire was utilized. The rubber injection gives added strength to the wire assembly and resists breakdown of the wire caused by concrete slurry. This 15mm diamond wire is constructed with 40 beads per meter and a 4.9mm base cable. Pictures of the diamond bead and wire assembly are shown below.

With diamond wires in the range of 100m long and plenty of contact area, wire speeds were moderate, or approximately 1200m/min. Pressure on wire was relatively low to maintain wire speed and deal with concrete slivers and debris in cut line. Gage pressure at the power unit was in the range of 2000 psi. Connections in butt joints of wires were monitored and replaced at 2-4 hour intervals. Cutting was generally performed around the clock to minimize impact of the structure changing. ■

SUMMARY Diamond wire cutting systems are the best known means for making slots in mass concrete structures. Maintaining slots at Mactaquac Generating Station is an effective way of dealing with distress caused by AAR. Continued improvements in diamond wire and equipment technology are increasing the efficiency of performing this work.

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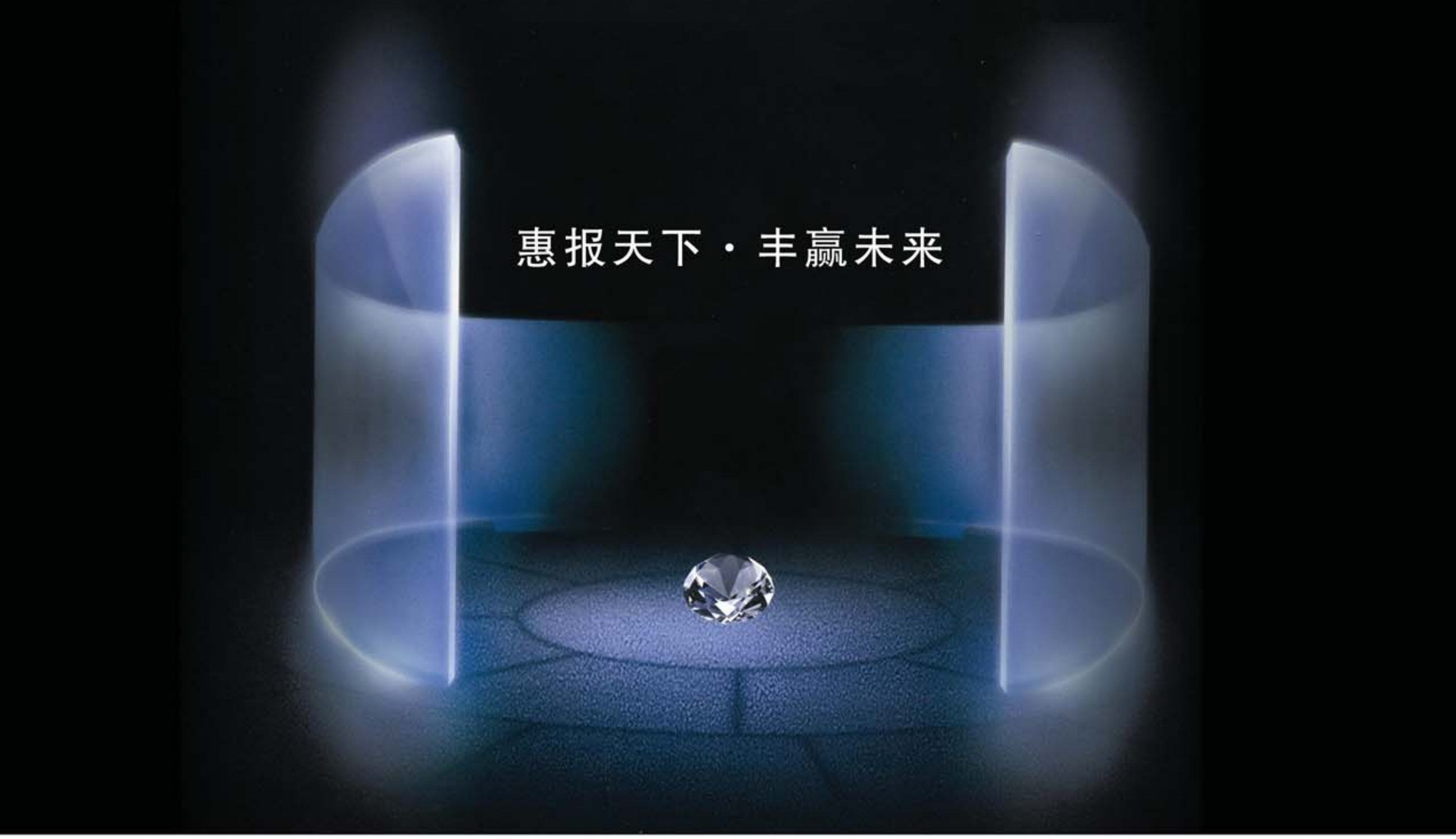
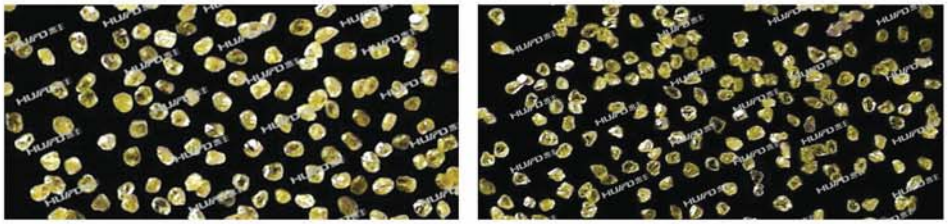
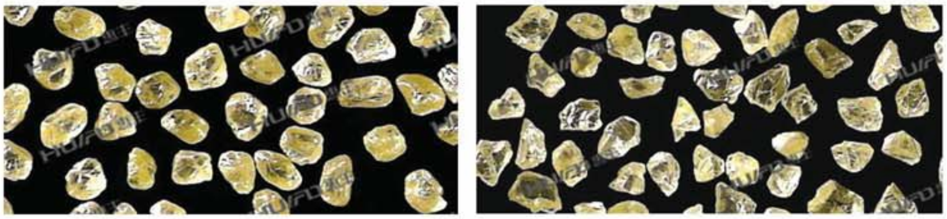


Diamond Micron Powder



Diamond Mesh Powder



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NEW CUTTER TECHNOLOGY Improves Performance 30-70% in Existing PDC Drill Bit Designs

By: Dan Scott, Anthony DiGiovanni, PhD, Nicholas Lyons, Derek Nelms – Baker Hughes Inc.

PCD

The use of PDC bit technology began in the 1970's. By 1980, less than two percent of the footage drilled in oil and gas was by PDC bits. After the introduction of the anti-whirl bit around 1990, there was a step change in the performance and significant increase in the market share of PDCs to just over five percent. Continued improvements throughout the 90's such as the introduction of non-planar interfaces (NPI's) and improved processing of PDC continued the trend. By 2000, bit designs were targeted to specific applications and cooperation between R&D, engineering, and field personnel further supported the gains of PDCs. In the past decade PDC bits have grown from approximately 25-30% of the market to near 75-80% of the oil and gas drill bit market (see Figure 1).

The steady market penetration of PDC bits observed in the 1980-2000 period was a combination of incremental performance improvements in cutter technology, and occasional step changes in technology. Intense competition was driven by new PDC cutter variants, computer modeling of the fluid flow, residual stress management, chamfered cutters, polished cutters, thicker diamond tables, broader cutter size range availability, improved rig hydraulics, and significantly improved understanding of the applications.

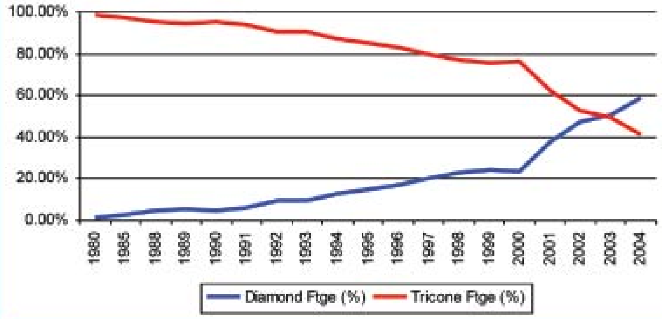

Figure 1: History of PDC footage drilled compared to roller cone (Tricone) footage; PDC footage continues to increase and supplant roller cone footage.

In the early 2000s a lot of focus was placed on the bit and cutter technologies and applications were re-evaluated with several opportunities for improvement identified. Several new technologies were developed such as layered cutter technology and others that were packaged with detailed understanding of the drilling environment and formation logs. The availability of this information and continued pressure to improve performance lead to the DART (design, application, review, technology) process of application specific bits designed with the customer's input and their particular drilling program and objectives taken into account for a customized bit design. New cutters were developed in close cooperation with the PDC cutter manufacturers for specific target applications, and the bit designers were no longer limited to a vendor's limited PDC cutter product requiring compromises in design or application parameters to meet the expected drilling objectives. This technology package was well received by the industry and led to a step change in the penetration of PDC into the bit market in the early 2000s.

Further developments in depth of cut control for dynamic stability in inter-bedded formations, features to increase steerability for directional wells, more stable designs, cutter manufacturing improvements, further expansion in the application specific cutter program, and rediscovery and commercialization of the 1980s work by Drs. Yazu and Nakai from Sumitomo on partially leached thermally stable cutters. Combined, these technologies and continued focus on the application parameters and improved downhole motors led to further improvements in better BHA modeling and assembly design.

This paper will highlight three case studies of recent improvements in PDC bit performance from three different approaches and technology packages in the Rocky Mountain basins. Improved bit design technology with existing cutters, improved cutters in existing bits, and a third case where the bit and cutter technology are substantially unchanged, but the application parameters were optimized through a detailed analysis of foot-based drilling data. Foot based data (FBD) consists of digital records collected at the drilling rig of weight on bit, RPM, torque, formations, and where available bit dynamics. Such data when available from the customer is matched to the formation logs and analyzed in detail by experts. The behavior of the bit and the response to the weight on bit and rpm with resulting changes in rate of penetration, dynamic stability, as it goes through various rock strata are determined. For example, as a bit drills through alternating hard and soft formations, a significant change in the response of the drill string can be realized from either the ease of drilling into a soft rock from hard or vice versa. Substantial changes in the instantaneous rate of penetration (ROP) can subject a PDC bit to very harsh and rapid loading, which in turn could cause damage to the PDC cutters and ultimately contribute to the shortening of the life of the bit.

After a detailed analysis of these run parameters and responses from the foot based data, the customer is then supplied with optimized parameters for hydraulics, WOB and RPM, BHA design, and recommendations for new tools like high performance motors, or rotary steerable systems (RSS) where applicable. Major improvements may be gained in bit life, and ROP if these guidelines are followed. In other cases, not the subject here, this FBD is used to optimize the bit design, and to pick the best cutter technology for the formation controlling the bit life. This is an extension of the DART process above where close cooperation of the customer with the bit company, and bit company with the cutter vendor, can lead to step-changes in drilling performance. As the shale gas market and its dependence on horizontal wells continues to increase, the necessity to get application specific bit designs for the horizontal, build, curve, and lateral sections have grown similarly.

Cutter Improvements Case Study:

In the Uintah Basin, in the northeast of Utah, synthetic polycrystalline diamond (PCD) cutting elements are extensively used to drill the intermediate section of natural gas wells. The section is an approximately 7,000ft long moderate drilling application in terms of difficulty, given the average formation strengths and relatively predictable drill bit performance. The intermediate section consists of mostly shale and sandstone formations ranging in strength from 5,000 to 10,000psi unconfined compressive strength (UCS) with several interbedded hard and abrasive sand and limestone stringers that can be

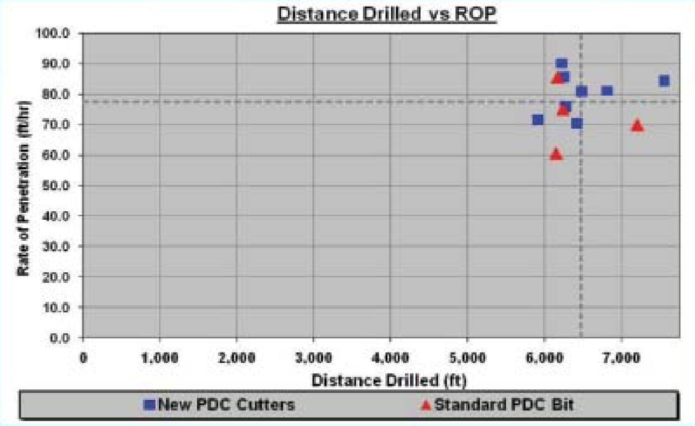

Figure 2: PDCs in the test area typically averaged 6,500ft with an average penetration rate of 71 ft/hr for the first bit in the section (red). The new PCD cutters showed an improvement in the average depth pulled of 200-300ft and a 10-15% improvement in the average ROP (blue).

upwards of 15,000 to 20,000psi UCS. Regardless of the drill bit manufacturer in 2010, drilling the entire intermediate section required two fixed cutter bits roughly 70% of the time. PCD cutting structure wear and general breakdown was similar among all fixed cutter drill bits as they would begin to wear in the sand portions of the section and then chip after repeated periods of unstable drilling instigated by the interbedded hard stringers. In general the first bit drilled 70% to 80% of the section and the second bit would complete the section drilling through the last hard interbedded sands before the targeted production zone. The biggest potential for differentiable performance and benefit to the operator was to increase the speed and consistency of drilling the intermediate section and by eliminating a trip to replace a worn bit.

Collaboration between the customer, field engineering support and product R&D facilitated analysis of the drill bit performance and identification of the PCD breakdown details. Abrasive wear of the PCD cutting elements began in sand formations due to the crystalline structure of sands which typically resist the shearing cutting mechanism of fixed cutter drill bits more than shale formations. The increased resistance to shear cutting action in sands requires more energy to fail the rock and generates more frictional forces in the PCD/rock interaction which generate higher temperatures at higher loads. These higher loads and elevated temperatures caused the standard 2010 PCD cutting element to breakdown in an unpredictable manner. The unpredictable dulling nature of the cutter led to a fair amount of variance in the length of the first bit run. A key component of the PCD breakdown in this type of environment is the thermal stability of the PCD structure which directly influences the diamond's ability to resist the microcrack events which in turn facilitates the wear process and eventual coalescence of damage leading to stress concentration points in the wearscar. These stress concentration points or flaws created in the PCD surface increase the cutting elements' susceptibility for crack generation and propagation on the macroscopic scale as the elements are subjected to dynamic loading events from drilling abruptly into formations of varying strengths. In order to prolong the life of the cutting elements, the PCD structure needed an increase in thermal stability and toughness. From this detailed analysis and collaborative dull cutter study between the bit company and its PDC supplier, a new PCD cutting element prototype was developed with this target in mind and tested. Most of the field testing occurred in one area of the Uinta Basin with a single operator using the same drill bit design they most commonly used in Uinta County. Running the tests so close together with one operator allowed for better performance comparisons and a case study of the new PCD cutting element influence. The standard fixed cutter drill bit design run in the test area as of Q1 2010 typically averaged 6,500ft with a standard deviation of 507 ft at an average penetration rate of 71 ft/hr for the first bit in the section (Figure 2, red).

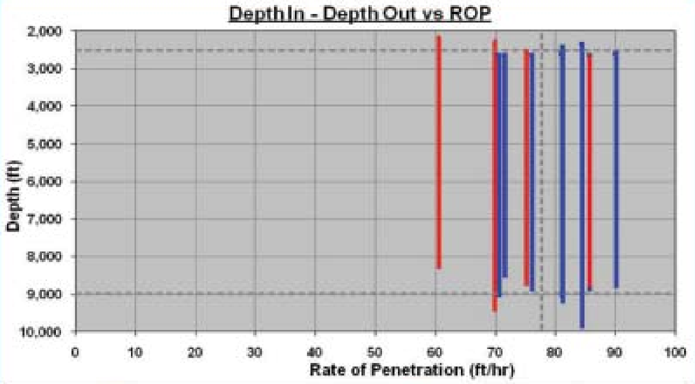

Figure 3: The new PDC cutters continued the trend in this part of Uinta County with an average depth out of over 150ft and 12% increase in average rate of the penetration.

The new PCD cutters were initially tested in Q2 2010 and within the first three runs they showed an improvement in the average depth pulled of 200-300ft and a 10-15% improvement in the average rate of penetration (Figure 2, blue). The operator requested more bits to expand testing and the bit company and PDC cutter manufacturer continued refinement of the prototype grade and by Q4 the new PDC cutter's performance improvement was measureable. The new PDC cutters continued the trend in this part of Uinta County throughout the remainder of 2010 with an average depth out of over 150ft and 12% increase in average rate of the penetration as shown in Figure 3.

These runs also showed a considerable improvement in drilling depth consistency decreasing the variation from run to run by almost 30% (actual decrease in variation was 28.9%). This means the operator was drilling deeper, more reliably and at a faster rate of penetration than before.

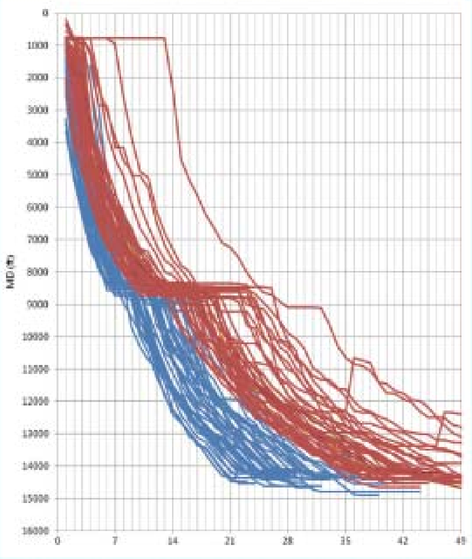

Figure 4: New cutters in the Pinedale application, increased ROP to between 40 and 50 feet per hour and distance drilled to around 2,500 feet per bit (blue) compared with the traditional impreg bit design (red).

Bit Design Improvement Case Study

The Pinedale anticline is a low permeability "tight" gas reservoir located approximately 75 miles Northwest of Rock Springs, Wyoming. To minimize impact on the environment multiple wells are drilled from a pad in an S-shaped curve with a 6 inch reservoir section occurring between 7,500 ft to 13,700 ft true vertical depth (TVD). The reservoir section is interbedded sandstones and shales, and is drilled overbalanced with mud weights up to 15 pounds per gallon. As a result of the depth and heavy mud weight the confined compressive strength (CCS) of the rock generally ranges between 50,000 psi and 70,000 psi with some areas reaching a CCS of up to 100,000 psi. The hard abrasive sands have historically been slow and difficult to drill, often requiring several bits for the reservoir section. Significant material and design changes have allowed vast improvements in the drilling performance, reducing the time in this interval by more than 100 hours per well. The hardness and abrasivity of the sand and shale sequences in the reservoir section present significant challenges to polycrystalline diamond compact (PDC) cutters. A cutter that resists abrasive wear is required to achieve increased rates of penetration (ROP) and footage drilled for each bit run. Furthermore, the application requires a cutter that maintains cutting efficiency and

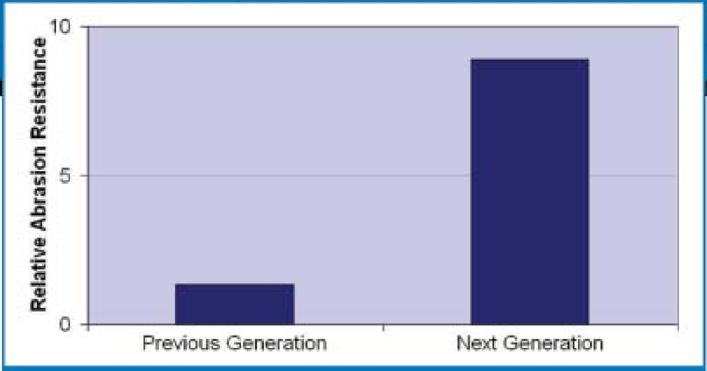

Figure 5: Improvements in the grain size distribution of the diamond feed for the next generation cutters demonstrated an increase in the abrasive wear resistance with rock lathe testing, which was also realized in the application.

resists fracture as it wears. Prior to 2009, there was not a cutter that met the above criteria. The reservoir section was drilled with diamond impregnated bits at a ROP averaging around 12 feet per hour and a distance of around 300 to 400 feet per bit (Figure 4, red).

In the past few years the introduction of enhanced PDC cutters addressed the abrasion and fracture requirements of the application, allowing the reservoir section to be drilled more efficiently. Modifications in the diamond feedstock and optimization of the sintering conditions produced cutters with notable increases in abrasive wear resistance. Researchers improved the grain size distribution of the diamond feed, showing an increase in the abrasive wear resistance with rock lathe testing as shown in Figure 5. Multiple iterations were designed to identify the best combination of grain size and sintering conditions, finally producing a PDC cutter with extensively higher wear resistance. Also, the diamond table thickness was decreased and the interface was optimized in order to further enhance performance of the cutters. A thinner diamond table maintains drilling efficiency throughout the life of the PDC cutter by reducing the surface area contact, or foot print, to the formation when the cutter is in a worn state. Also, the interface design allowed the internal stresses to be balanced more effectively when the PDC cutter is in the worn state. This allows the cutter to resist fracture and premature failure in the drilling environment, providing more reliable performance from bit to bit. By introducing new cutters to the Pinedale application, ROP in the reservoir section was increased to between 40 and 50 feet per hour, and distance drilled per bit was increased to around 2,500 feet per bit compared with the traditional impreg bit design (Figure 4, blue).

Subsequently, an effort was launched in 2010 to improve overall performance in the reservoir section, including ROP, distance drilled, and dull condition at the end of the run by improving the bit design. Drilling companies often record data throughout the course of the bit run, called footbased data. Analysis of the data can reveal where inefficiencies occur in the bit to rock interaction, such as PDC cutter wear, rubbing of the matrix on the formation, or inadequate bit cleaning. In a well known field, such as the Pinedale Anticline, foot-based data can be coupled with the lithology (rock information) of the application to deduce what types of inefficiencies were hurting performance in that application. For example, if a bit slows down considerably in a shale section, one can assume the bit is not being adequately cleaned, as shales are typically softer than other rock types and their cuttings tend to stick or clump together in a phenomenon known as "bit balling". The bit balling can drastically reduce or even stop the flow of cutting fluid in the circulation loop back to the surface, which will dramatically change the drilling conditions or even cause a need for the run to be stopped altogether. Using the foot based data is essential in creating effective drill bit designs for an application.

Analysis of the foot-based data for the reservoir section in the Pinedale Anticline revealed the bits were not being cleaned effectively in the shale segments of the formation, the bit matrix was rubbing on the formation throughout the run, and the PDC cutters wore prematurely in one section of the cutting structure. In order to correct this, a more aggressive, more easily cleaned design was created with a cutting structure that balanced the work load more evenly across its entirety. Computational fluid dynamics (CFD) were used to determine the best hydraulic system for cleaning the bit. The new design has increased ROP to between 50 and 60 feet per hour and has increased to between 2,700 and 3,000 feet – all with the same cutter type which had been used in the previous design.

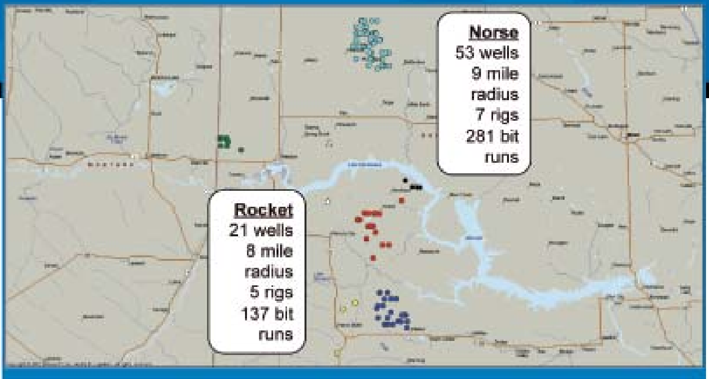

Figure 6: In 2010 a detailed study was done by the engineers for a bit company in close cooperation with an operator who had provided access to their drilling data in the Williston Basin in the northern plains.

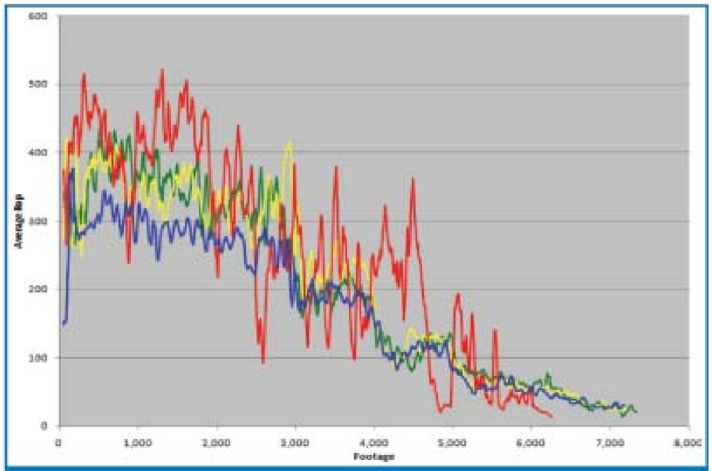

Figure 7: The formations in this area are especially challenging with a high degree of heterogeneity as shown by the average ROP logs for a variety of operators in that section.

Application Optimization Case Study:

As mentioned earlier the operators record a variety of parameters during the drilling of a well. When these records are matched up with the lithology logs for the formation, the experienced engineer can perform a foot-based review of the run identifying where the bit is being run at less than optimum parameters, or where the bit is encountering damage, wear, balling etc. Bit balling, for example is the accumulation of rock cuttings in the open passageways of the bit. If the accumulation of cuttings becomes too severe, it can start to affect the rate of penetration of the bit through the rock or even halt it altogether, depending on the type of rock being drilled and the extent of the problem. In 2010 a detailed study was done by the engineers for a bit company in close cooperation with an operator who had provided access to their drilling data in the Williston Basin in the northern plains (see Figure 6). The cooperative effort, which expanded over the previous year, lead to substantial improvement in drilling performance across the Williston Basin after implementing the results of the study. Operators are drilling horizontal wells with typical total depths around 20,000 ft including the following sections: 12-1/4 inch or 13-1/2-inch surface hole, an 8-3/4-inch vertical and curve section, and a 5 7/8-inch or 6-inch horizontal drain section in the reservoir. The vertical and curve sections include both shale and dolomite formations resulting in substantially different requirements for optimum performance. The two dominant formations in the horizontal sections are the Middle Bakken and the Three Forks, both dolomites. The Middle Bakken tends to drill more consistently than the more difficult-to-drill Three Forks formation. Major challenges for operators in this area are to consistently drill each section of the wellbore with one bit efficiently. The formations in this area are especially challenging with a high degree of heterogeneity as shown by the average ROP logs for a variety of operators in that section (Figure 7). The ROP varies wildly and decreases significantly with increased footage drilled. The challenges in this area include: varying formation depths and thicknesses in the vertical, a technically challenging curve section and a horizontal section with a strict production zone location. The spread of performance from well to well in the same areas are considerable. In working with major operators across the Williston Basin, the service company has developed a systematic approach to closely analyze current performance. A detailed analysis using foot-based data as the foundation of the study with dull bit photo analysis and ETS (Electronic Tour Sheets) were used to discover the ideal operating parameters for each hole section and for specific areas of the basin. These parameters provided a systematic approach to constructing the most efficient wellbore possible. The operator-provided data after analysis is presented to the rig floor personnel in a way that improvements in consistency and efficiency can easily be obtained. In some cases modifications to the existing bit frames have also been made as a result of the study to provide further performance improvements. This process is currently in place with a major operator in the basin and has produced results that produced substantial improvements in performance and consistency. When wells in the same area are considered, and outliers are excluded, the vertical section alone shows a 71% spread from best performing well to worst. This difference has allowed the service company and operators to work together to consistently decrease the drilling hours required to construct the wellbore. The same process is being applied to the other sections, with results of up to 50% reduction in time to drill the long horizontal lateral section already being realized (Figure 8).

With the optimized drilling parameters, and designs adapted to these 3 section wells, it is now possible to focus in on the critical cutter behaviors and begin a cutter optimization process between the PDC cutter vendor and the bit company to further improve ROP and consistency, again reducing the cost to drill these complex wells.

CONCLUSIONS:

Since their first introduction in the 1970's, PDC drill bits have increasingly become the standard bit of choice for most drilling applications in oil and gas fields around the world. Substantial improvements in bit designs, application understanding, and PDC cutter technology have delivered step changes in bit performance. The optimization of PDC cutter grain size, interface structure, and manufacturing parameters continue to move bit performance upwards when properly applied. Similarly, the use of foot-based data is a valuable tool for the optimization of operating parameters and for identifying opportunities for bit design improvements. It has been shown that improvement in bit performance can be obtained through a variety of processes, with cutter technology being one of the key areas to realize significant gains. ■

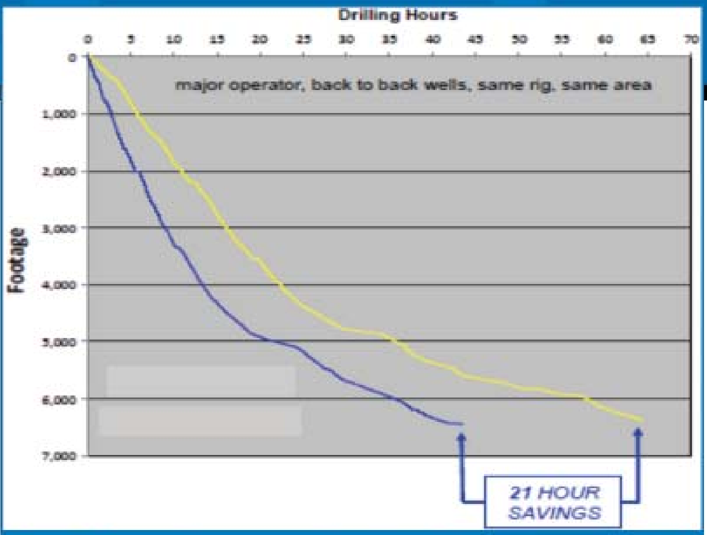

Figure 8: The service company and operators worked together, consistently decreasing the drilling hours required (up to 50% reduction in time to drill the long horizontal lateral) and saving as much as 21 hours overall.

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Study of the Influence of Cobalt Content on Polycrystalline Diamond (PCD) Mechanical Properties

J. DANIEL BELNAP, YI FANG and HAIBO ZHANG – MegaDiamond, A Schlumberger Company

Polycrystalline diamond (PCD) has distinct advantages in mechanical properties over traditional engineering ceramics, i.e., comparatively high strength and toughness. Also, the extreme high wear resistance makes PCD an indispensable material for gas/oil drilling and mining applications, as well as in high precision cutting tools. Pushing the limit of the material performance boundary of PCD is in many cases the key to success in these applications. In this study, a model PCD material system is investigated using the standard PCD manufacturing technology in the diamond stable region by varying the content of the secondary catalyst metal phase. The influence of the metal content to mechanical properties of PCD as well as wear resistance is covered.

INTRODUCTION

The use of polycrystalline diamond (PCD) has become of increasing importance in the rock drilling and metal cutting industries in the recent decades. The outstanding wear resistance of this material combined with its intrinsic mechanical properties makes it indispensable in many of these applications. Contributions to the fundamental understanding of the properties of PCD have been made by various researchers. For example, Lammer and Huang, et al reported the effects of grain size on fracture toughness and flexural strength. It was shown in these studies that fracture toughness and flexural strength of PCD have an inverse relationship with grain size, similar to most engineering material systems. Huang further pointed out that the metal content in the PCD materials had an inverse relationship to grain size. The smaller grain sizes corresponded to a higher metal content and a lower fracture toughness compared to materials with larger grain size. This suggested that the effect of metal content on PCD toughness is either insignificant or small in comparison to the grain size effect.

However, the effect of metal content in PCD is generally expected to provide some toughening asset from analogy with other brittle materials containing a ductile metal phase. For example, the stretching of ductile metallic ligaments contributes to significant toughening in both the Al_2O_3/Al system and WC/Co system. Further circumstantial evidence for a toughening effect has been presented through comparative functional testing of products made with the same grain size but varying metal content. Enhanced insert products made with these materials have given higher impact resistance. The use of higher cobalt content materials in improving performance and further expanding the application of PCD into new applications has been reported. However, despite the evidence for improved product performance in selected applications with higher cobalt containing materials, the effect of metal content on actual PCD fracture toughness is not clear. The possibility that better field performance may be achieved simply due to abrasive removal of surface cracks has been discussed in these papers, which would effectively improve performance through a mechanism of properly tailored/engineered wear resistance with the application. The purpose of this paper is to determine the effect of metal content on PCD material properties, particularly fracture toughness, independent of grain size.

EXPERIMENTAL PROCEDURES

Since the inception of cobalt-sintered diamond materials several decades ago, the general sintering procedures for PCD have become well known. In this study, a mixture of diamond powders with particle size of 4-8 µm and premixed cobalt powders of 10 & 20 wt% were placed in contact with a WC-11wt% Co substrate and placed in a refractory metal container within a high pressure/high temperature cell. The cell was sintered at approximately 5.5 GPa and 1400 °C, which are conditions well known to be within the diamond stable region of the carbon phase diagram. The sintered PCD samples were then lapped to remove the WC-Co substrate, resulting in a sample thickness of around 2.5 mm.

Microstructural analysis on the PCD material was performed by mounting and polishing the samples with progressively finer diamond pastes down to 1 µm and subsequently examining the samples using scanning electron microscopy (SEM). The density of PCD samples was measured using Archimedes principle, and the Co/W ratio of the sintered PCD parts was obtained from energy dispersive spectroscopy (EDS) analysis. Carbon is well known to be particularly difficult to characterize accurately using EDS techniques, however the relative amounts of cobalt and tungsten can be determined with reasonable accuracy. Because of this, a technique was employed to determine the PCD composition based on the

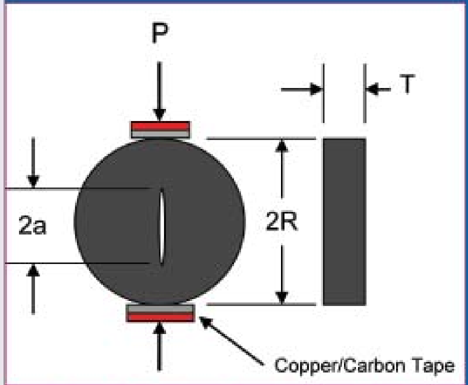

Figure 1. Specimen dimensions and loading configuration used in fracture toughness testing.

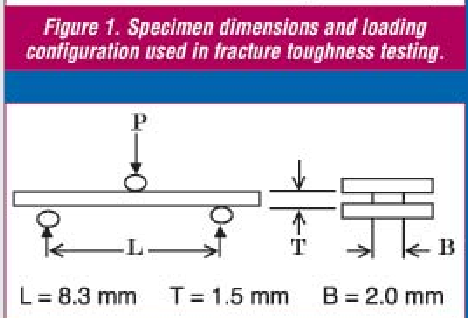

Figure 2. Testing specimens and configuration of three-point bending test.

Measured Density (g/cm³)	Co/W Ratio from EDS	CalculatedCo Vol%
4.235	4.65	10.0
4.291	6.89	12.0

Table 1. Densities and calculated Co volume fractions.

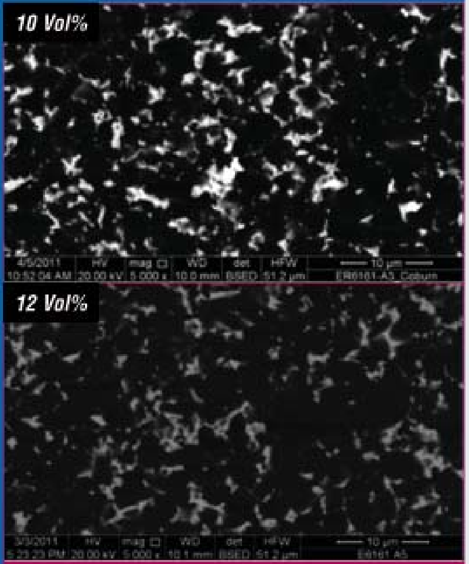

Figure 3. SEM micrographs of the PCD materials.

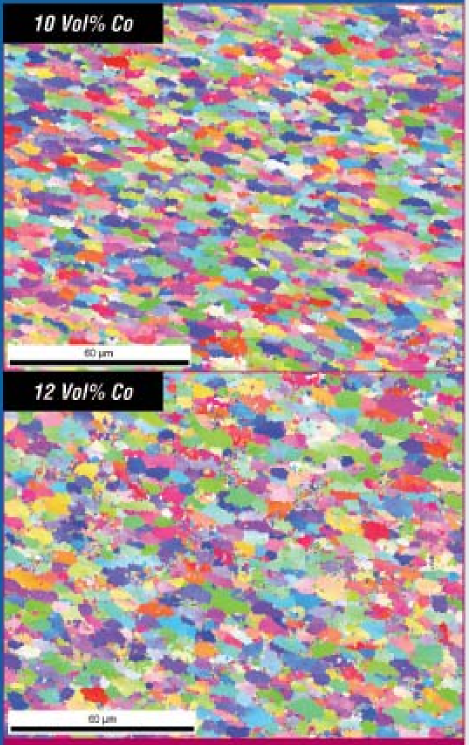

Figure 4. EBSD mapping for the PCD materials.

Material	Average Diamond Grain Size (µm)
10% Vol	4.30
12% Vol	5.17

Table 2. Grain size measurement from EBSD analysis

measured density, the measured ratio of Co/W, and the known densities of diamond, cobalt, and tungsten carbide. The volume fraction of Co phase in the sintered PCD parts was determined according to the following equations. In these equations, k = mco/mw , where mco and mw are the mass fractions of the cobalt and tungsten determined from EDS. The following equations were used to calculate the mass fractions of the diamond (mdia), cobalt (mco), and tungsten carbide (mwc) in the PCD body:

$$m_{dia} = 1 - \frac{(\rho_{dia} - \rho)}{\rho}\left[\frac{\rho_{co}\rho_{wc}(k+1)}{\rho_{dia}\rho_{co} + \rho_{wc}\rho_{dia}k - \rho_{wc}\rho_{co}(k+1)}\right]$$

$$m_{co} = \frac{(\rho_{dia} - \rho)}{\rho}\left[\frac{\rho_{co}\rho_{wc}k}{\rho_{dia}\rho_{co} + \rho_{wc}\rho_{dia}k - \rho_{wc}\rho_{co}(k+1)}\right]$$

$$m_{wc} = \frac{(\rho_{dia} - \rho)}{\rho}\left[\frac{\rho_{co}\rho_{wc}}{\rho_{dia}\rho_{co} + \rho_{wc}\rho_{dia}k - \rho_{wc}\rho_{co}(k+1)}\right]$$

where: ρ_{dia} = 3.51 gm/cc, ρ_{co} = 8.85 gm/cc, ρ_{wc} = 15.7 gm/cc, and ρ = measured density of the PCD sample. With these calculated mass fractions, the final volume fractions of diamond (v_{dia}), cobalt (v_{co}) and tungsten carbide (v_{wc}) were then calculated using the following equations:

$$v_{dia} = \left[\frac{m_{dia}/\rho_{dia}}{m_{dia}/\rho_{dia} + m_{co}/\rho_{co} + m_{wc}/\rho_{wc}}\right]$$

$$v_{co} = \left[\frac{m_{co}/\rho_{co}}{m_{dia}/\rho_{dia} + m_{co}/\rho_{co} + m_{wc}/\rho_{wc}}\right]$$

$$v_{wc} = \left[\frac{m_{wc}/\rho_{wc}}{m_{dia}/\rho_{dia} + m_{co}/\rho_{co} + m_{wc}/\rho_{wc}}\right]$$

Electron backscatter diffraction (EBSD) analysis is a microstructural-crystallographic technique used to determine the crystallographic orientation of materials by identifying and indexing the electron backscattering diffraction pattern from the polished sample surface. EBSD analysis was performed using Orientation Image Microscopy (OIMTM), a commercial software package used in conjunction with an electron microscope (FEI, Model Inspect F). EBSD is used to reveal texture, preferred grain orientation, crystal defects and grain boundaries and has been previously employed to study PCD materials (LaDue, 2006). In this study, EBSD analysis was used primarily to provide numerical estimation of the diamond grain size in the PCD samples.

Fracture toughness samples were made using diametral compression specimens from the sintered and lapped PCD samples. Diametral compression has been used to measure the fracture toughness of PCD material previously and was selected for this study because of the comparative ease of sample preparation compared to other techniques. To prepare the specimens, a Nd-YAG laser was used to cut the samples to an outer diameter (2R) of 12.7 mm with a through notch (2a) of 6.13 mm long, with a thickness T = 2.5 mm. The specimens were then positioned and loaded to failure using the configuration shown in figure 1. Note that a combination of copper and adhesive carbon tape was used to keep samples aligned and to provide sufficient compliance to avoid damage to the edges of the PCD disks during compressive loading. A displacement rate of 0.5 mm/min was employed. In this test, no precracking was performed on the specimens, so crack propagation initiated from the sharp notch during the loading process. The fracture toughness was determined according the following formula:

$$K_{IC} = \frac{P_c\sqrt{\pi a}}{\pi RT}N_1$$

where P_c is the fracture load, a is the half length of the through slot, R is the radius of the disk specimen, T is the specimen thickness, and N_1 is given by

$$N_1 = 0.991 + 0.141(a/R) + 0.863(a/R)^2 + 0.886(a/R)^3$$

Flexural strength testing was performed on laser cut rectangular specimens to measure the flexural strength of the PCD materials. Efforts to remove the laser damaged area were taken to eliminate surface defects in critical regions of the test specimens. The tension surface of the specimens was lapped with 12 - 22 µm diamond paste prior to testing. Testing was performed with a three-point bending apparatus on a screw-driven universal testing machine with a loading rate of 0.05 mm/min. The nominal specimen size and testing configuration are shown in figure 2.

The flexural strength σ_f of an individual test specimen was given by

$$\sigma_f = \frac{3PL}{2BT^2}$$

where P was the load required to fracture the specimen and L, B, and T are dimensions defined in figure 2.

Wear resistance was performed on the test specimens made from the sintered compacts by grinding/machining to a nominal dimensions of 19 mm diameter and 8 mm height. Testing was performed by placing the specimens in a tool holder at a 15° backrake and turning the OD of a Barre granite cylinder. The testing parameters were 0.02 inch depth of cut and 400 feet/min of surface speed under flood-cooling conditions. The amount of granite removed was determined by measuring the diameter of the granite log before and after the test in multiple locations. The amount of abrasive material removed was determined by making measurements of the wear scar using an optical microscope and estimating the removed volume using a numerical algorithm. The ratio of granite material removed to abrasive material removed was the experimentally-measured wear resistance or G-ratio of the abrasive material.

EXPERIMENTAL RESULTS

Analysis of the two types of PCD materials investigated in this study is shown in table 1 and figure 3. These materials have the same nominal grain size but different secondary phase content in the final microstructure. The material with the higher premixed cobalt amount (20 wt%) resulted in a 12 vol% cobalt, while the 10 wt% premixed cobalt contained 10 vol%. The higher amount of cobalt can be seen in the density and Co/W ratios as well.

Figure 3 shows SEM micrographs of the 10 vol% and 12 vol% Co materials. In the SEM micrographs, the materials were observed to have similar diamond grain size (dark phase). The other phases visible are cobalt (grey phase) and WC (bright phase). It can be seen that the secondary phase (Co and WC) in the 12 vol% sample are slightly higher than that of 10 Vol% sample.

Figure 4 shows the EBSD mapping of the studied PCD materials with 10 Vol% Co and 12 Vol% Co. There was no diamond phase or Co phase texture found in the sintered materials, rather the diamond grains were randomly distributed. Grain size measurements are tabulated in Table 2. Table 2 shows that the diamond average grain size of the 12 Vol% grade is also little coarser than that of 10 Vol% grade.

The flexural strength, fracture toughness and wear resistance of these two materials are listed in Table 3. Table 3 shows that simultaneous increases of flexural strength and fracture toughness with the increase of Co volume content, but a decrease in wear resistance.

DISCUSSION

The wear resistance results showing a decrease in wear resistance with an increase in cobalt content were fully expected, as this is highly dependent on the diamond volume fraction of the PCD material. The slightly finer grain size seen with EBSD analysis likely had some minor contribution to the wear resistance results as well. The EBSD analysis determined that the grain size in the case of the 10 vol% samples was smaller by approximately 20%. Likely this is due to the effect of the HP/HT process during the pressurization stage. In the case of the 10 vol% samples there was initially 10 wt% cobalt blended with the diamond powder, while the 12 vol% samples had 20 wt% cobalt was blended with the powder. Fracture of diamond grains during the HP/HT sintering process is well known. However, the relatively soft cobalt powder additive acts to cushion the diamond particles from grain to grain contact, thus reducing the amount of fracturing. It is therefore expected that a PCD material with a higher amount of cobalt blended

Material	Flexural Strength (MPa)	Fractured (MPa $m^{1/2}$)	Wear Resistance (G Ratio)
10 Vol%	1159 ± 59	9.03 ± 0.18	0.83 ± 0.08 ($*10^6$)
12 Vol%	1475 ± 99	9.94 ± 0.48	0.48 ± 0.01 ($*10^6$)

Table 3. Mechanical properties & wear resistance of studied PCD materials.

Sample	Residual Stress (MPa)	Flexural Strength (MPa)
10 Vol% Co	-694 ± 79	1159 ± 59
12 Vol% Co	-1000 ± 93	1475 ± 99

Table 4. Comparative residual stress and flexural strength values.

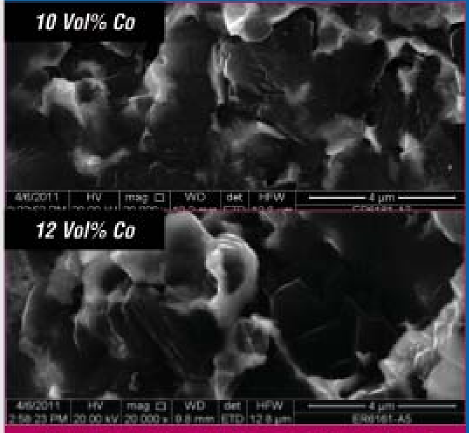

Figure 5. Fracture surfaces of PCD specimens showing increased ductility of cobalt phase on higher cobalt volume fraction material.

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with the diamond powder would have a reduced amount of fracturing and a larger grain size, as seen in the tests. The measured fracture toughness values are slightly higher than given by an interpolation of Lammer's results using the diametral compression technique. This is due to the higher amount of premixed metal in the samples, as it can be seen from comparative densities. The densities of PCD body in this study are significantly higher than those reported by Lammer. The simultaneous increase of both flexural strength and fracture toughness in both the 10 vol% and 12 vol% samples warranted further investigation to better understand the underlying mechanisms. To accomplish this, residual stresses in the materials were studied using Raman spectroscopy. The surfaces of the as-sintered materials were probed using 785 nm laser excitation (Process Instruments, Inc, Model PI-200-L-HP) to determine residual stress differences between the 10 vol% and the 12 vol% PCD material. Raman spectroscopy is commonly used to determine residual stresses in diamond-based materials by quantitative determination of the shift in the 1332.5 cm-1 Raman peak. The Raman peak is known to shift with applied stresses according the relation

$$\Delta\omega = \frac{\omega_0\gamma}{B}\sigma_H$$

where $\Delta\omega$ is the relative peak center shift between the stressed and unstressed material, w_0 is the equilibrium peak center located at 1332.5 cm^{-1}, γ is the Grunesian parameter which is equal to - 1.06, B is the bulk modulus of diamond which is 442 GPa, and σ_H is the hydrostatic stress given by

$$\sigma_H = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$$

where σ_1, σ_2, and σ_3 are the principle stresses. In the case of measuring stresses on surfaces one of the principle stresses is zero due to the free surface effect (i.e. $\sigma_3 = 0$). Also in making surface stress measurements is reasonable to assume for comparative purposes that the remaining in plane stresses are equivalent $\sigma_1 = \sigma_2 = \sigma_B$. Substituting these values into the hydrostatic stress expression, placing these into equation 3 and solving for σ_B gives the following

$$\sigma_B = \frac{3\Delta\omega B}{2\omega_0\gamma}$$

The peak center was determined by fitting a Gaussian curve to the diamond Raman peak. Calibration was performed by use of a neon spectral lamp and simultaneous monitoring of an unstressed single crystal diamond as reference peak in an independent channel on the CCD array during data collection. The neon lamp provided continuous calibration of the spectrometer gratings against changes in ambient temperature, while the diamond reference provided calibration against shifts in the internal laser frequency during the experiment. The measured residual stresses in the 10 vol% and 12 vol% PCD materials using Raman spectroscopy are shown in table 4. Measured surface stresses in PCD by the Raman technique are known to be affected by the surface state of the material. As such, it should be noted that all measurements were made on as-pressed surfaces after being subjected to a silicon carbide grit blast. Because of this, some amount of surface compression can be attributed to the blasting process – therefore for the purposes of this investigation more attention should be paid to the relative differences between the samples than the absolute numbers. Compression in the diamond phase is reasonable because the sintering of diamond and cobalt phases at high temperatures entails a cooling from 1450 °C to room temperature. The thermal expansion coefficient of diamond ($1.5 - 4.8 * 10^{-6}$ between 400 K and 1200 K) is relatively low while cobalt ($15.7 – 16.8 * 10^{-6}$ between 473 K and 1023 K) has a relatively high thermal expansion coefficient. As a direct result of the sintering operation, mutual interfacial constraints and internal equilibrium result in the diamond phase being in compression and the cobalt phase being in tension. It can be seen that the compressive stresses in the 12 vol% PCD material was 306 MPa higher relative to the 10 vol% PCD material. It is reasonable that the sample with a higher volume fraction of cobalt gives higher compressive stresses than the lower volume fraction sample because the tensile forces caused by stress/strain in the higher volume fraction cobalt phase must be balanced by a counteracting internal compressive force in a lower volume fraction of diamond, which results in a larger compressive stress. It can be seen in table 4 that the differences in measured compressive stress are very similar to the differences in measured flexural strength between the two sample groups (306 MPa vs. 316 MPa). In a flexure test of a brittle material like PCD, it is well known that the material fails in tension. Therefore, it is expected that a material with a higher state of internal compression in the brittle phase would fail at a higher level of flexural strength, which is consistent with the results. It should be noted that the observed EBSD grain size differences did not provide an explanation for higher strength in the 12 vol% samples, as based on previous work a larger grain size should give a lower flexural strength. Therefore, it appears that higher internal compression from the cobalt phase provided the most reasonable explanation for the flexural strength results.

To further understand the fracture toughness results, high resolution scanning electron microscopy work on fracture surfaces was performed using a field emission SEM (FEI Inc, Model Inspect F). Micrographs of the 10 and 12 vol% samples are shown in figure 5. The most notable differences can be seen in the behavior of the apparent ductility of cobalt phase on these samples. It can be seen that on the 12 vol% samples cobalt ligaments have clearly stretched in a ductile manner relative to the surrounding diamond particles on the fracture surface, whereas this behavior on the 10 vol% samples is less pronounced. This ductile stretching has been previously observed in the cobalt phase of WC-Co materials and is theorized to be responsible for significant toughening in this materials system.

The fracture toughness results in this experiment appear to have three possible contributing mechanisms: 1) cobalt ductility, 2) residual stress, and 3) grain size. As mentioned previously, the contribution of ductile metals in toughening brittle materials has been noted in other materials systems. The specific mechanism involves the stretching of metal ligaments behind the crack tip, thus providing significant resistive forces opposing crack opening and increasing the amount of crack opening force needed to fracture the material. It should be noted that the diametral compression method used to evaluate fracture toughness may not have fully exploited the full effect of cobalt ductility toughening, since the specimens were not precracked and the most significant effect of ligament toughening occurs behind a pre-existing crack tip and increases with an increase in crack length, resulting in what is known as R-curve behavior. In addition to the cobalt ductility mechanism, the toughening effect of residual compressive stresses is well known in the behavior of brittle materials such as ceramics and glasses. Examples of this include tempered glass and transformation toughening in ZrO_2 ceramics. Other ceramic systems have incorporated residual compressive stresses similar to the differences seen between the samples in this test, which have shown measurable increases in toughness. Based on these results, it is expected that the relative increase in compressive stress seen in the 12 vol% samples should give some toughening effect as well. Finally, the slightly larger grain size of the 12 vol% material, that as discussed previously is likely due to the crushing effect during processing, may have had a small contribution as well. More experimentation is needed to fully understand the effects of these mechanisms on PCD toughness. ■

CONCLUSIONS

Significant differences were seen between the 10 and 12 vol% samples in: Wear Resistance, Flexural Strength and Fracture Toughness. Possible mechanisms for the improved mechanical properties in the 12 vol% samples are: Compressive Residual Stress, Cobalt Ligament Ductility and Grain Size.

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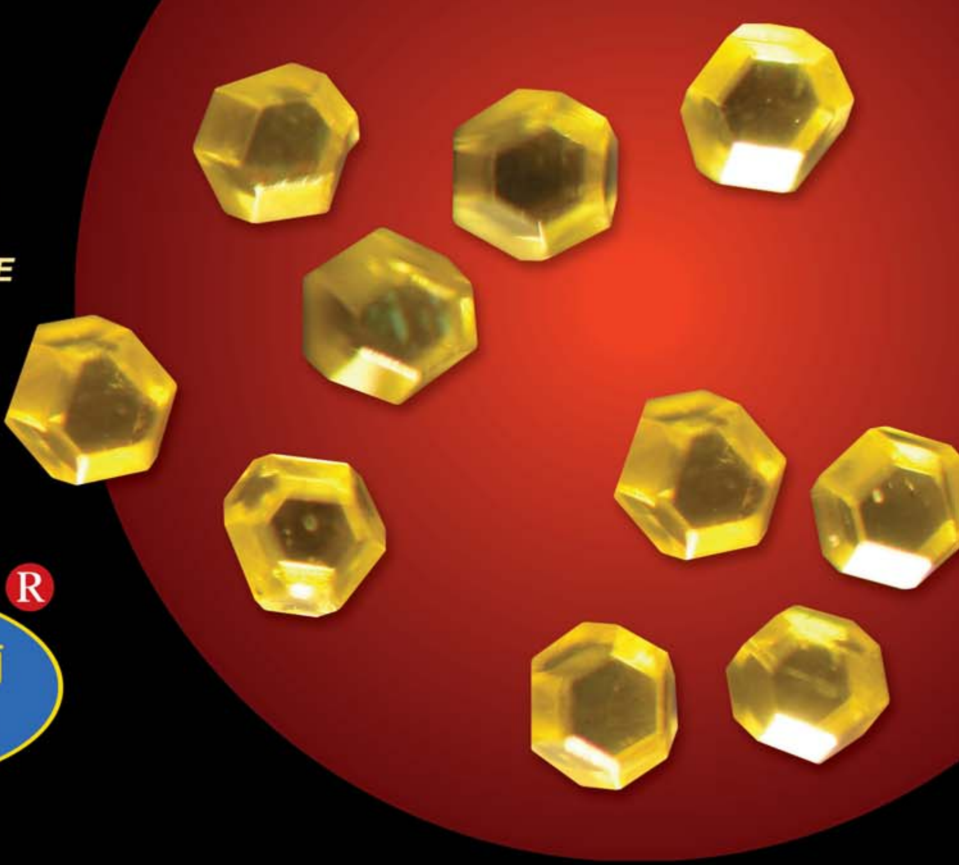

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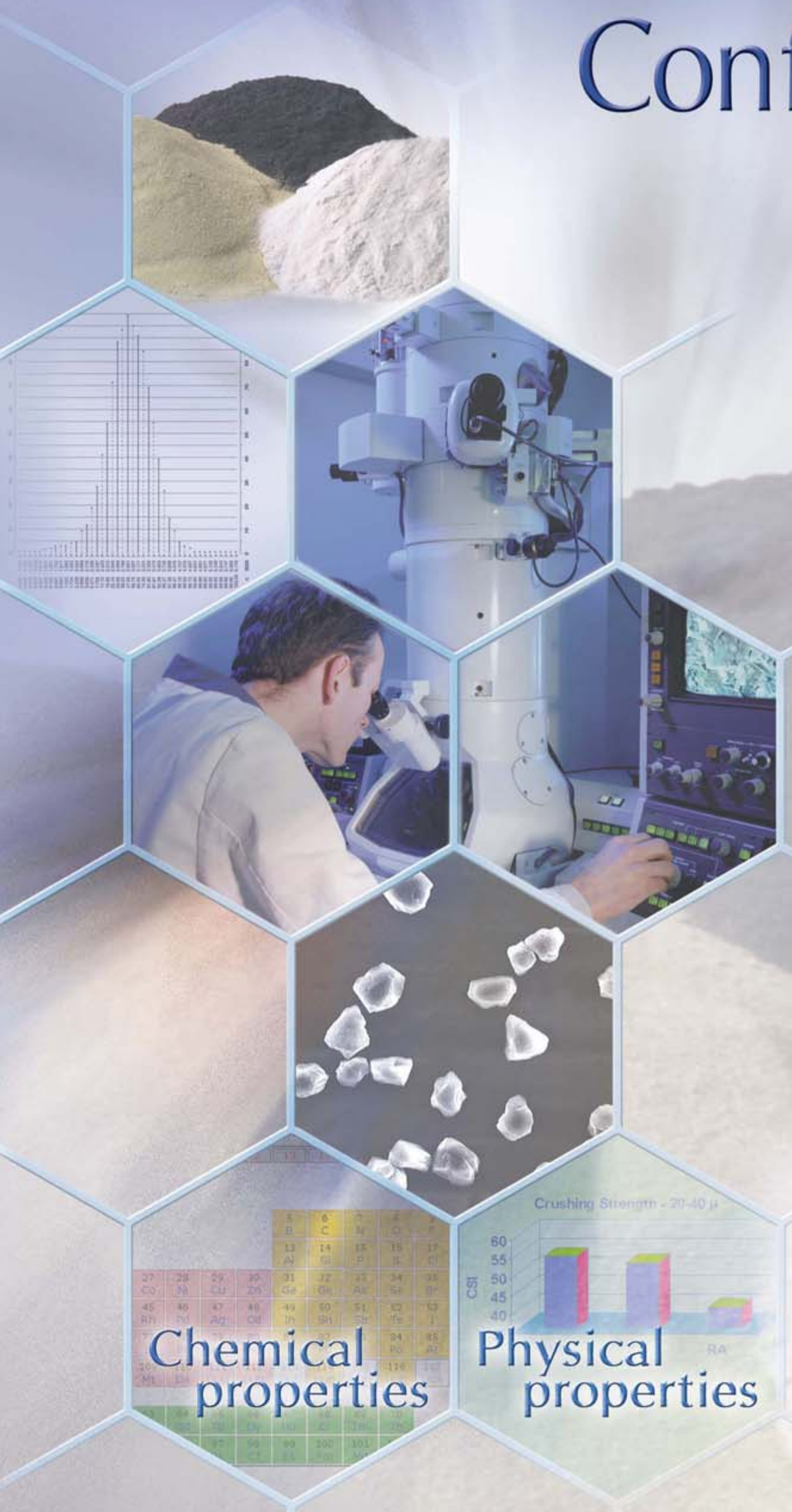

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